BULLETIN

OF THE

GEOLOGICAL SOCIETY

OF

AMERICA

VOL. 32

JOSEPH STANLEY-BROWN, *Editor*

NEW YORK
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1921

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ILLUSTRATIONS

Plates

Figures

(12 plates; 60 figures.)

PUBLICATIONS OF THE GEOLOGICAL SOCIETY OF AMERICA

Regular Publications

The Society issues annually, in four quarterly parts, a single serial octavo publication entitled Bulletin of the Geological Society of America, the edition being 750 copies. A small supply of authors' separates of the longer articles is kept for sale by the Secretary at the prices quoted in each volume.

The Bulletin is sold at the uniform price of ten dollars ($10.00) per volume, with a discount of twenty-five (25) per cent to Fellows of the Society. A discount of ten (10) per cent is allowed to persons residing elsewhere than in North America and public and institutional libraries; carriage extra. Subscriptions are payable in advance. Regular subscribers within the United States of America and its possessions receive their parts, postage paid, as issued. Forty (40) cents per volume must be added to the subscription price to cover postage to other countries in the Postal Union.

The price of the index to volumes 1-10 is $2.25; to volumes 11-20, $3.50, and to volumes 21-30, $4.00; carriage extra. No reduction is made to dealers. Orders should be addressed to the Secretary, whose address is care of the American Museum of Natural History, New York, N. Y., and drafts and money orders should be made payable to *The Geological Society of America.*

Description of the Published Volumes

Volumes.	Pages.	Plates.	Figures.
Vol. 1, 1889	593 + xii	13	51
Vol. 2, 1890	622 + xiv	23	63
Vol. 3, 1891	541 + xi	17	72
Vol. 4, 1892	458 + xi	10	55
Vol. 5, 1893	655 + xii	21	43
Vol. 6, 1894	528 + x	27	40
Vol. 7, 1895	558 + x	24	61
Vol. 8, 1896	446 + x	51	29
Vol. 9, 1897	460 + x	29	49
Vol. 10, 1898	534 + xii	54	83
Index to volumes 1–10	209	..	..
Vol. 11, 1899	651 + xii	58	37
Vol. 12, 1900	538 + xii	45	28
Vol. 13, 1901	583 + xii	58	47
Vol. 14, 1902	609 + xii	65	43
Vol. 15, 1903	636 + x	59	16
Vol. 16, 1904	636 + xii	94	74
Vol. 17, 1905	785 + xiv	84	96
Vol. 18, 1906	717 + xii	74	59
Vol. 19, 1907	617 + x	41	31
Vol. 20, 1908	749 + xiv	111	35
Index to volumes 11–20	422	..	..
Vol. 21, 1909	823 + xvi	54	109
Vol. 22, 1910	747 + xii	31	66
Vol. 23, 1911	758 + xvi	43	44
Vol. 24, 1912	737 + xviii	36	60
Vol. 25, 1913	802 + xviii	28	47
Vol. 26, 1914	504 + xxi	27	41
Vol. 27, 1915	739 + xviii	30	55
Vol. 28, 1916	1005 + xxii	48	102
Vol. 29, 1917	679 + xix	22	67
Vol. 30, 1918	644 + xiii	15	40
Index to volumes 21–30	325	..	..
Vol. 31, 1919	450 + xviii	14	7
Vol. 32, 1920	488 + xviii	12	60

Parts of Volume 32

Reprints.	Pages.	Plates.	Figures.	Price to Fellows.	Price to Public.
mber 1	1–196	1	10	$2.60	$3.90
mber 2	197–314	....	15	1.90	2.80
umber 3	315–358	....	9	1.00	1.50
umber 4*	359–488	11	26	2.20	3.30

Reprints from Volume 32

Reprints.	Pages.	Plates.	Figures.	Price to Fellows.	Price to Public.
Proceedings of the Thirty-third Annual Meeting of the Geological Society of America, held at Chicago, Illinois, December 28-30, 1920. E. O. Hovey, *Secretary*	1–118	1	10	$1.50	$2.25
Proceedings of the Twelfth Annual Meeting of the Paleontological Society, held at Chicago, Illinois, December 28-30, 1920. R. S. Bassler, *Secretary*†	119–156	....	...	.50	.75
Proceedings of the First Annual Meeting of the Society of Economic Geologists, held at Chicago, Illinois, December 28-29, 1920. J. Volney Lewis, *Secretary*	157–162	....	...	.15	.25
Proceedings of the First Annual Meeting of the Mineralogical Society of America, held at Chicago, Illinois, December 29, 1920. H. P. Whitlock, *Secretary*	163–170	....	...	.15	.25
Important epochs in the history of petroleum and natural gas. I. C. White	171–186	....	...	.20	.30
Origin of South American faunas. F. B. Loomis	187–196	....	...	.15	.25
Groundwork of the earth's diastrophism. T. C. Chamberlin	197–210	....	...	.20	.30
The greater earth. T. C. Chamberlin	211–226	1–4	...	.30	.45
Geology and geography in the United States. E. B. Mathews and H. P. Little	227–248	1–4	...	.35	.50
Igneous geology of southeastern Idaho. G. R. Mansfield	249–266	1–3	...	.30	.45
Pre-Cambrian rocks of Manitoba. F. J. Alcock and E. L. Bruce	267–292	....	1–3	.40	.60
Windrow formation; an upland gravel formation of the driftless and adjacent areas of the upper Mississippi Valley. F. T. Thwaites and W. H. Twenhofel	293–314	....	1	.35	.50

* Preliminary pages and index are distributed with number 4.

† Under the brochure heading is printed Proceedings of the Paleontological Society.

Reprints.	Pages.	Plates.	Figures.	Price to Fellows.	Price to Public.
Observations on the mode of life of primitive cephalopods. R. Ruedemann†	315–320	....	1–9	$0.15	$0.25
Status of our knowledge of Mesozoic pathology. R. L. Moodie†	321–326	....	...	.15	.25
Evolution, phylogeny, and classification of the Mastodontoidea. H. F. Osborn†	327–332	....	...	.15	.25
Criteria for the determination of the climatic environment of extinct animals. E. C. Case†	333–338	....	...	.15	.25
Method of determining the relationships of marine invertebrate fossil faunas. C. Schuchert†	339–348	....	...	.15	.25
Criteria for species, phylogenies, and faunas of trilobites. P. E. Raymond†	349–352	....	...	.15	.25
Criteria for determination of climate by means of fossil plants. F. H. Knowlton†	353–358	....	...	.15	.25
Impressions made by bubbles, rain-drops, and other agencies. W. H. Twenhofel	359–372	....	1–7	.20	.30
Syngenetic origin of concretion in shale. W. A. Tarr	373–384	....	1–2	.15	.25
Some conclusions in regard to the origin of gypsum. F. A. Wilder	385–394	....	...	.15	.25
On metamorphism in meteorites. G. P. Merrill	395–416	2–6	...	.50	.75
Solitario uplift, Presidio-Brewster counties, Texas. S. Powers	417–428	....	1–3	.15	.25
Increased oceanic salinity as one cause of increased climatic contrasts. S. S. Visher	429–436	....	...	.15	.25
Sweet Grass Hills, Montana. J. F. Kemp and P. Billingsley	437–478	7–12	1–14	.80	1.20

† Under the brochure heading is printed Proceedings of the Paleontological Society.

Irregular Publications

In the interest of exact bibliography, the Society takes cognizance of all publications issued wholly or in part under its auspices. Each author of a memoir receives 40 copies without cost, and is permitted to order any additional number at a slight advance on cost of paper and presswork; and these reprints are identical with those of the editions issued and distributed by the Society; but the cover bears only the title of the paper, the author's name, and the statement [Reprinted from the Bulletin of the Geological Society of America, vol. —, pp. —, pl. — (Date)]. Contributors to the Proceedings and "Abstracts of Papers" are also authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork; but such separates are bibliographically distinct from the reprints issued by the Society.

Regular Editions

Pages	171–186,		250	copies.	March	31, 1921.
"	187–196,		200	"	"	31, 1921.
"	197–210,		170	"	June	30, 1921.
"	211–226,		170	"	"	30, 1921.
"	227–248,		100	"	"	30, 1921.
"	249–266,		150	"	"	30, 1921.
"	267–292,		300	"	"	30, 1921.
"	293–314,		170	"	"	30, 1921.
"	315–320,*†		300	"	September	1, 1921.
"	321–326,*†		200	"	"	1, 1921.
"	327–332,*†		400	"	"	1, 1921.
"	333–338,*†		250	"	"	1, 1921.
"	339–348,*†		410	"	"	1, 1921.
"	349–352,*†		200	"	"	1, 1921.
"	353–358,*†		200	"	"	1, 1921.
"	359–372,		110	"	December	1, 1921.
"	373–384,		300	"	"	1, 1921.
"	385–394,		100	"	"	1, 1921.
"	395–416,	plates 2– 6,	50	"	"	1, 1921.
"	417–428,		100	"	"	1, 1921.
"	429–436,		150	"	"	1, 1921.
"	437–478,	plates 7–12,	200	"	"	1, 1921.

Special Editions ‡

Pages	59– 62,	50	copies.	March	31, 1921.
"	75– 80,	150	"	"	31, 1921.
"	81– 83,	100	"	"	31, 1921.
"	83– 86,	100	"	"	31, 1921.
"	105–118,	600	"	"	31, 1921.
"	119–156,*†	160	"	"	31, 1921.
"	157–162,	50	"	"	31, 1921.
"	163–170,	150	"	"	31, 1921.

* Bearing on the cover

PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY.

[Reprinted from the Bulletin of the Geological Society of America, vol. ——, pp. ——, pls. ——, (Date).]

† Under the brochure heading is printed PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY.

‡ Bearing imprint [From Bull. Geol. Soc. Am., Vol. 32, 1920.]

CORRECTIONS AND INSERTIONS

Contributors to volume 32 have been invited to send corrections and insertions to be made in their papers, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 2, line 10 from top, *omit* "Structural features of Indiana" and *insert* Increased oceanic salinity as one cause of increased climatic contrasts.

" 16, line 3 from top, *insert* Ph. D. after name of John L. Tilton.

" 26, line 18 from bottom, *for* "subsequently" *read* consequently.

" 26, line 21 from bottom, *for* "sympathy" *read* symmetry.

" 27, line 6 from bottom, *omit* "Structural features of Indiana" and *insert* Increased oceanic salinity as one cause of increased climatic contrasts.

" 27, line 5 from bottom, *after* "Stephen" *insert* initial S.

" 27, lines 2, 3, and 4 from bottom, and

" 28, lines 1 to 28 from top, *transfer* to page 35 and *insert* by W. N. Logan under title "Some structural features of Indiana."

" 52, *insert* in footnote Lamplugh, G. W.: On glacial shell-beds in British Columbia. Proceedings of the Yorkshire Geological Society, 1886.

" 93, line 24 from top, *insert* the name of J. L. Tilton among the Fellows-elect present at the meeting.

" 157, The "Proceedings" of the Chicago meeting of the Society of Economic Geologists were made up by the Secretary of the Geological Society of America, and the footnote (line 30) should be transferred to page 158, as referring merely to the program of papers and the Constitution and By-Laws.

" 172, line 10 from top, *for* "wooden" *read* woolen.

" 263, center of figure 3, under "S" of "Sugarloaf," *insert* short perpendicular line to indicate separation of igneous and sedimentary rocks.

" 270, in "Tabulated Summary" facing this page, first word in first column, *for* "Athahapuskow" *read* Athapapuskon.

" 289, line 4 from top, *after* Ontario *insert* comma.

" 347, line 2 from top, *after* "Euro-Asiatic one" *insert* of late Middle and.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 32, PP. 1-118, PL. 1 MARCH 31, 1921

PROCEEDINGS OF THE THIRTY-THIRD ANNUAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT CHICAGO, ILLINOIS, DECEMBER 28-30, 1920.

EDMUND OTIS HOVEY, *Secretary*

CONTENTS

Session of Tuesday, December 28, 1920

The Thirty-third Annual Meeting of the Geological Society of America as held December 28-30, 1920, in Chicago, Illinois, in affiliation with le Seventy-third Annual Meeting of the American Association for the

Advancement of Science. In affiliation with the Geological Society, the Paleontological Society convened in its Twelfth Annual Meeting, the Mineralogical Society of America held its First Annual Meeting, and the Society of Economic Geologists held its First Annual Meeting. All the business and scientific sessions and the annual subscription smoker were held in the rooms of Rosenwald Hall by invitation of the Department of Geology of the University of Chicago. The annual subscription dinner took place at the Chicago Beach Hotel.

The first general session of the meeting was called to order at 9.50 o'clock a. m., Tuesday, December 28, 1920, by President I. C. White, and the Secretary was called on for the report of the Council. This was submitted in printed form, as follows:

REPORT OF THE COUNCIL

To the Geological Society of America, in thirty-third annual meeting assembled:

The regular annual meeting of the Council was held at Boston, Massachusetts, in connection with the meeting of the Society, December 29-31, 1919. A special meeting was held in Washington, April 25, 1920.

The details of administration for the thirty-second year of the existence of the Society are given in the following reports of the officers:

SECRETARY'S REPORT

To the Council of the Geological Society of America:

The Secretary's annual report for the year ending November 30, 1920, is as follows:

Meetings.—The proceedings of the annual general meeting of the Society, held at Boston, Massachusetts, December 29-31, 1919, have been recorded in volume 31, pages 1-196, of the Bulletin, and of the Paleontological Society, pages 197-232, of the same volume.

Membership.—During the past year the Society has lost one Fellow by death—Joseph P. Iddings. The names of the fifteen Fellows elected at the Boston meeting, and who qualified, have been added to the printed list. The present enrollment of the Society is 419. Thirty-five candidates for Fellowship are before the Society for election and several applications are under consideration by the Council.

Index.——An index volume to volumes 21 to 30, inclusive, of the Bulletin has been compiled and printed under the supervision of the Editor, and it will be distributed early in the year 1921.

Distribution of the Bulletin.—There have been received during the year fifteen new subscriptions to the Bulletin; forty-four have not yet been renewed. The number of volumes sent out to subscribers is now 138. Five volumes are distributed gratis to the Library of Congress, the American Museum of Natural History, and the government geological surveys of the United States, Canada, and Mexico.

The irregular distribution of the Bulletin during the past year has been as follows: Complete volumes sold to the public, 198; sent out to supply delinquents, 3; brochures sold to Fellows, 56; sold to the public, 186; sent out to supply delinquents, 53, and deficiencies, 30. Index to volumes 1-10 sold to the public, 2; Index 11-20, 2.

Bulletin sales.—The receipts from subscriptions to and sales of the Bulletin during the past year are shown in the following table:

Bulletin Sales, December 1, 1919–November 30, 1920

	Complete volumes.			Brochures and parts.			Grand total.
	Fellows.	Public.	Total.	Fellows.	Public.	Total.	
Volume 1...	....	$15.00	$15.00	....	....	....	$15.00
Volume 2...	....	22.50	22.50	$3.00	....	$3.00	25.50
Volume 3...	....	22.50	22.50	....	....	....	22.50
Volume 4...	....	30.00	30.00	.30	....	.30	30.30
Volume 5..	....	30.00	30.00	.34	$3.00	3.34	33.34
Volume 6...	....	30.00	30.00	....	....	....	30.00
Volume 7...	....	22.50	22.50	....	.35	.35	22.85
Volume 8...	....	22.50	22.50	....	....	....	22.50
Volume 9...	....	22.50	22.50	....	....	....	22.50
Volume 10...	....	22.50	22.50	.65	1.00	1.65	24.15
Volume 11...	....	30.00	30.00	....	....	....	30.00
Volume 12...	....	30.00	30.00	....	....	....	30.00
Volume 13...	....	30.00	30.00	....	....	....	30.00
Volume 14...	....	30.00	30.00	....	.15	.15	30.15
Volume 15...	....	30.00	30.00	....	....	....	30.00
Volume 16...	....	37.50	37.50	.11	.90	1.01	38.51
Volume 17...	....	7.50	7.50	....	1.80	1.80	9.30
Volume 18...	....	7.50	7.50	.35	1.30	1.65	9.15
Volume 19...	....	7.50	7.50	....	.67	.67	8.17
Volume 20...	....	50.00	50.00	....	7.00	7.00	57.00
Volume 21...	....	7.50	7.50	3.00	2.80	5.80	13.30
Volume 22...	....	32.50	32.50	5.15	....	5.15	37.65
Volume 23...	....	15.00	15.00	.70	1.05	1.75	16.75
Volume 24...	....	32.50	32.50	....	11.68	11.68	44.18
Volume 25...	....	15.00	15.00	....	1.90	1.90	16.90
Volume 26...	....	15.00	15.00	2.60	4.29	6.89	21.89
Volume 27...	....	37.50	37.50	3.00	6.54	9.54	47.04
Volume 28...	....	47.50	47.50	5.70	71.93	77.63	125.13
Volume 29...	....	38.00	38.00	5.40	13.35	18.75	56.75
Volume 30...	....	127.50	127.50	27.25	363.83	391.08	518.58
Volume 31...	....	667.50	667.50	.15	....	.15	667.65
Volume 32...	....	175.50	175.50	....	....	....	175.50
Total....	....	$1,711.00	$1,711.00	$57.70	$493.54	$551.24	$2,262.24
Index 1–10..	....	4.50	4.50	....	....	....	4.50
Index 11–20..	....	7.00	7.00	....	....	....	7.00
Total....	....	$1,722.50	$1,722.50	$57.70	$493.54	$551.24	$2,273.74

Charged on 1919 account, but not yet received....................	$3.00
Charged on 1920 account, but not yet received....................	163.20
Total..	$166.20
Receipts for the fiscal year..	$2,107.54
Previously reported..	24,967.04
Total sales to date..	$27,074.58

Expenses.—The following table gives the cost of administration and of Bulletin distribution during the past year:

EXPENDITURES OF SECRETARY'S OFFICE DURING THE FISCAL YEAR ENDING NOVEMBER 30, 1920

Account of Administration

Printing and stationery	$204.00	
Postage	52.98	
Telegrams and telephone	25.14	
Repairs to typewriter and dictaphone	3.25	
Express	.77	
Bookbinding	2.75	
Geological Magazine	5.10	
Group portrait (postage, messenger, and printing)	10.80	
Group portrait	40.00	
Loss on foreign exchange	.37	
Sundries connected with Boston meeting	12.07	
Total		$357.23

Account of Bulletin

Preparation of Index to volumes 21-30	$390.00	
Clerical hire authorized by Council	300.00	
Postage	56.50	
Express	19.53	
Addressograph plates	3.58	
Telegrams	1.17	
Printing	2.00	
Messenger	.65	
Exchange on checks	2.70	
Total		776.13
Grand total		$1,133.36

Respectfully submitted,

EDMUND OTIS HOVEY,
Secretary.

TREASURER'S REPORT

To the Council of the Geological Society of America:

The Treasurer herewith submits his annual report for the year ending November 30, 1920.

The membership of the Society at the present time is 419, of whom 331 pay annual dues. Eighteen new members were elected at the last

annual meeting, fifteen of whom qualified, one as a Life Member. There has been one death, a Life Member, during the year, which leaves the total of Life Members at 88. Two members were dropped for the non-payment of dues. When the books closed for the year, 27 members were delinquent in the payment of dues—1 for 4 years, 2 for 3 years, 5 for 2 years—and are therefore liable to be dropped from the roll, and 19 for 1 year.

RECEIPTS

Cash on hand, December 1, 1919		$3,361.02	
Fellowship fees, 1918 (3)	$30.00		
1919 (10)	100.00		
1920 (303)	3,030.00		
1921 (1)	10.00		
		3,170.00	
Life Commutation (1)		150.00	
Initiation fees (15)		150.00	
Interest on investments		1,195.00	
Interest on deposits in Baltimore Trust Company		147.28	
Collection charges added to checks		.20	
Received from Secretary:			
Sales of publications	$2,107.54		
Sales of group portrait	422.25		
Subscriptions to Geological Magazine	232.70		
Postage and express	41.02		
Authors' separates	316.75		
Authors' corrections	76.71		
Illustration work charged to authors	10.38		
Collection of checks	3.26		
Brazilian Government on account Portuguese edition of geological map of Brazil	166.60		
		3,377.21	
			$11,550.71

EXPENDITURES

Secretary's office:			
Administration	$301.33		
Bulletin	776.13		
Group portrait	50.80		
Geological Magazine	231.30		
Secretary's allowance	1,000.00		
		$2,359.56	
Treasurer's office:			
Expenses	$37.25		
Clerk	150.00		
		187.25	

Publication of Bulletin:

Printing	$3,680.57			
Engraving	185.48			
Editor's allowance............	250.00			
		4,116.05		
Purchase of one Louisville & Nashville Railroad Company 10-year 7 per cent note; one New York Central Railroad Company 10-year 7 per cent Collateral Trust bond; one Bell Telephone Company of Pennsylvania 25-year First and Refunding 7 per cent bond		3,113.44		
			$9,776.30	
Balance in Baltimore Trust Company, December 1, 1920.			1,774.41	
				$11,550.71

Respectfully submitted,

EDWARD B. MATHEWS,
Treasurer.

EDITOR'S REPORT

To the Council of the Geological Society of America:

The following tables cover statistical data for the thirty-one volumes thus far issued:

ANALYSIS OF COSTS OF PUBLICATION

Cost.	Average—Vols. 1-25.	Vol. 26.	Vol. 27.	Vol. 28.	Vol. 29.	Vol. 30.	Vol. 31
	pp. 759. pls. 42.	pp. 525. pls. 27.	pp. 757. pls. 30.	pp. 1027. pls. 48.	pp. 698 pls. 22	pp. 657 pls. 15	pp. 468 pls 14
Letter press..........	$1,807.41	$1,076.22	$1,684.67	$2,128.15	$1,483.37	$2,477.16	$1,541.45
Illustrations..........	327.04	171.69	378.30	484.37	321.07	917.56	131.94
Paper,..................	....	231.00	416.00	698.00	416.00	379.61	266.64
Total..............	$2,134.45	$1,478.91	$2,478.97	$3,310.52	$2,220.44	$3,773.33	$1,940.03
Average per page	$2.83	$2.81	$3.27	$3.23	$3.18	$5.75	$4.15

CLASSIFICATION OF SUBJECT-MATTER

Volume.	Areal geology.	Physical geology.	Glacial geology.	Physiographic geology.	Petrographic geology.	Stratigraphic geology.	Paleontologic geology.	Economic geology.	Official matter.	Memorials.	Unclassified.	Total.
	Number of Pages.											
1	116	137	92	18	83	44	47	-----	60	4	4	593+xii
2	56	110	60	111	52	168	47	9	55	1	7	662+xiv
3	56	41	44	41	32	158	104	-----	61	15	1	541+xii
4	25	134	38	74	52	52	14	-----	47	32	2	458+xii
5	138	135	70	54	28	51	107	-----	71	14	9	665+xii
6	50	111	75	39	71	99	1	-----	63	25	4	538+x
7	38	77	105	53	40	21	123	4	66	28	13	558+x
8	34	50	98	5	43	67	58	14	79	8	-----	46+x
9	2	102	138	-----	44	28	64	16	64	12	-----	60+x
10	35	33	96	37	59	62	68	28	84	27	17	534+xiii
11	65	110	21	10	54	31	188	7	71	60	46	651+xii
12	199	39	55	53	24	98	5	5	70	2	-----	538+xi
13	125	17	13	24	28	116	42	4	165	32	29	583+xii
14	48	47	48	59	183	118	22	1	80	14	1	609+xi
15	26	124	3	94	36	267	-----	-----	77	17	3	636+x
16	64	111	78	30	102	141	19	-----	67	22	15	636+xiii
17	49	161	41	84	47	294	27	-----	71	9	2	785+xiv
18	16	164	141	5	29	246	5	-----	68	40	3	717+xii
19	106	108	29	66	30	155	32	-----	56	15	20	617+x
20	43	54	35	29	37	45	303	8	60	3	132	749+xiv
21	72	234	75	48	85	70	106	1	111	11	10	823+xvi
22	23	54	28	28	23	403	74	-----	63	49	1	747+xii
23	75	52	126	108	19	145	134	-----	66	32	1	758+xvi
24	18	57	96	57	49	160	106	23	133	53	3	737+xviii
25	34	211	54	32	156	9	175	-----	108	9	22	802+xviii
26	-----	72	23	11	56	90	148	-----	54	44	6	504+xxi
27	1	59	125	31	146	20	271	2	73	24	5	739+xviii
28	25	273	70	69	78	200	55	39	94	110	14	1005+xxii
29	3	107	62	15	127	169	64	-----	73	57	21	679+xix
30	160	3	41	9	5	36	205	16	73	59	50	644+xiii
31	1	80	19	4	13	45	22	21	69	97	79	450+xviii

Respectfully submitted,

JOSEPH STANLEY-BROWN, *Editor.*

The foregoing report is respectfully submitted.

THE COUNCIL.

December 28, 1920.

On motion, this report, according to the custom, was laid on the table to the next day to permit the auditing of the Treasurer's accounts.

ELECTION OF AUDITING COMMITTEE

The Society then elected E. S. Bastin, J. T. Singewald, Jr., and F. B. Peck to serve as an Auditing Committee.

AMENDMENTS TO CONSTITUTION AND BY-LAWS

Announcement was made that the amendments to the Constitution and By-Laws which had been submitted to the Society by Council in order to provide for the representation on the council of societies accepted in affiliation with the Geological Society of America had been adopted, the vote standing 336 in favor to 4 against the amendments; 308 favorable votes are now necessary for the adoption of an amendment to the Constitution. The amendments are as follows:

The first sentence of paragraph 1 of Article IV of the Constitution is changed to read as follows:

The officers of the Society shall consist of a president, a first vice-president, a second vice-president, and one vice-president to represent each of the societies affiliated with this Society, a secretary, a treasurer, an editor, and six councilors.

The fourth sentence of section 1 of Chapter IV of the By-Laws is changed to read:

The nominee for third vice-president shall be the nominee for the presidency of the Paleontological Society, which has been organized as a section under Article VIII of the Constitution. The nominee for the vice-president representing an affiliated society shall be chosen from the joint fellowship by vote of the affiliated society concerned, subject to confirmation by the Council of the Geological Society of America.

The change became effective as of December 1, 1920, and the President of the Mineralogical Society of America automatically became the nominee for Fourth Vice-President of the Geological Society of America for 1921.

ELECTION OF OFFICERS FOR 1921

The Secretary then announced that the Council had on the preceding day canvassed, opened, and counted the ballots for officers for the year 1921, in accordance with the By-Laws, and he declared the list duly elected as follows:

OFFICERS FOR 1921

President:

JAMES F. KEMP, New York City

First Vice-President:

J. B. WOODWORTH, Cambridge, Massachusetts

Second Vice-President:

ARTHUR KEITH, Washington, D. C.

Third Vice-President:

T. W. Stanton, Washington, D. C.

Fourth Vice-President:

Charles Palache, Cambridge, Massachusetts

Secretary:

Edmund Otis Hovey, New York City

Treasurer:

Edward B. Mathews, Baltimore, Maryland

Editor:

Joseph Stanley-Brown, New Cork City

Councilors (1921-1923):

L. C. Graton, Cambridge, Massachusetts
George D. Louderback, Berkeley, California

ELECTION OF REPRESENTATIVES ON THE NATIONAL RESEARCH COUNCIL

The following Fellows were declared duly elected as nominees as representatives on the Advisory Committee of the National Research Council for the term July 1, 1921, to June 30, 1924, inclusive:

Rollin T. Chamberlin, Chicago, Illinois.
Frederick E. Wright, Washington, D. C.

ELECTION OF FELLOWS

The following persons were then declared to have been elected Fellows of the Society in accordance with the provisions of the Constitution and By-Laws:

Frederick James Alcock, B. A., Ph. D., Geologist, Geological Survey of Canada, Ottawa, Canada.

Harold Lattimore Alling, B. S., A. M., Ph. D., Assistant, Department of Geology, University of Rochester, Rochester, New York.

Edward Clayton Andrews, B. A., Chief, Geological Survey of New South Wales, Sydney, New South Wales.

Albert Dudley Brokaw, S. B., Ph. D., 157 Maplewood Avenue, Maplewood, New Jersey.

Everend Lester Bruce, B. Sc., B. A., A. M., Ph. D., Geologist, Geological Survey of Canada, Ottawa, Canada.

Walter H. Bucher, Ph. D., Assistant Professor of Geology, University of Cincinnati, Cincinnati, Ohio.

ERNEST FRANCIS BURCHARD, B. S., M. S., Geologist, U. S. Geological Survey, Washington, D. C.

JOHN PETER BUWALDA, B. S., Ph. D., Assistant Professor of Geology, Yale University, New Haven, Connecticut.

GILBERT HAVEN CADY, A. B., A. M., Ph. D., Department of Geology and Mining, Fayetteville, Arkansas.

WILLIAM O. CLARK, B. A., A. M., 771 Hamilton Street, Palo Alto, California.

GUY HENRY COX, B. S., M. A., Ph. D., Head of Department of Geology, Missouri School of Mines, Rolla, Missouri.

CHARLES LAWRENCE DAKE, A. B., A. M., Associate Professor of Geology, Missouri School of Mines, Rolla, Missouri.

NELSON CLARK DALE, B. Sc., M. A., Ph. D., Professor of Geology, Hamilton College, Clinton, New York.

ELMER FRED DAVIS, B. S., M. S., Ph. D., 1539 Bonita Avenue, Berkeley, California.

CARL OWEN DUNBAR, A. B., Ph. D., Instructor in Geology, University of Minnesota, Minneapolis, Minnesota.

ARTHUR EARL FATH, A. B., A. M., Associate Geologist, U. S. Geological Survey, Washington, D. C.

HENRY G. FERGUSON, A. B., B. S., A. M., Geologist, U. S. Geological Survey, Washington, D. C.

JESSE JAMES GALLOWAY, A. B., A. M., Ph. D., Instructor in Paleontology, Columbia University, New York City.

JULIA ANNA GARDNER, A. B., A. M., Ph. D., U. S. Geological Survey, Washington, D. C.

JAMES HAROLD HANCE, B. S., B. S. in Mining Engineering, E. M., Ph. D., 708 West Washington Boulevard, Urbana, Illinois.

CHARLES JOSEPH HARES, B. S., M. S., Geologist, the Ohio Oil Company, Casper, Wyoming.

KENNETH CONRAD HEALD, B. S., Associate Geologist, U. S. Geological Survey, Washington, D. C.

JAMES MADISON HILL, S. B., Geologist, U. S. Geological Survey, Washington, D. C.

WILLIAM S. W. KEW, B. S., M. S., Ph. D., Petroleum Geologist, U. S. Geological Survey, Washington, D. C.

CARLOTTA JOAQUIN MAURY, Ph. B., Ph. D., Paleontologist to the Brazilian Geological Survey, Hastings-on-Hudson, New York.

WILBUR ARMISTEAD NELSON, B. S., M. A., State Geologist, Tennessee Geological Survey, Nashville, Tennessee.

JOHN JOHNSTON O'NEILL, B. Sc., M. Sc., Ph. D., Geologist, Geological Survey of Canada, Ottawa, Canada.

WALLACE E. PRATT, A. B., B. S., A. M., E. M., Chief Geologist, Humble Oil and Refining Co., Houston, Texas.

SIDNEY POWERS, B. A., S. M., M. A., Ph. D., Chief Geologist, Amerada Petroleum Corporation, Tulsa, Oklahoma.

RALPH WEBSTER RICHARDS, A. B., M. A., Consulting Petroleum Geologist, Washington, D. C.

ELLIS WILLIAM SHULER, A. B., M. A., Ph. D., Professor of Geology, Southern Methodist University, Dallas, Texas.

Robert Browning Sosman, B. Sc., S. B., Ph. D., Physicist, Geophysical Laboratory, Washington, D. C.

John Littlefield Tilton, B. A., M. A., West Virginia University, Morgantown, West Virginia.

Bruce Wade, B. S., M. S., Ph. D., Assistant State Geologist, State Geological Survey, Nashville, Tennessee.

Herbert Percy Whitlock, C. E., Curator of Mineralogy, American Museum of Natural History, New York City.

CHANGES IN PUBLICATION RULES

Announcement was made that Council had changed Publication Rule No. 17 to read: "Authors may be charged for alterations ('authors' corrections') amounting to more than ten per cent of the original cost of composition and presswork of their papers"; and had changed Publication Rule No. 19 to read: "Authors of papers of more than four printed pages in length shall receive 40 reprints *gratis*."

SUPPORT OF THE GEOLOGICAL MAGAZINE

The Secretary reported that Council had voted to continue for the year 1921 its guarantee of forty subscriptions to the *Geological Magazine* of London, England, in order to assist in maintaining that time-honored periodical.

NECROLOGY

The President announced that the Society had lost but one Fellow during the year 1920, Joseph P. Iddings, and he called upon Henry S. Washington for an oral tribute to the deceased.

MEMORIAL OF JOAQUIM CANDIDO DA COSTA SENA

BY JOHN C. BRANNER

Dr. J. C. da Costa Sena was born in the city of Conceição do Serro, State of Minas Geraes, Brazil, August 13, 1852, and died at Bello Horizonte, in the same State, June 20, 1919. His early education was received at the Lazarist College, at Caraça, in the State of Minas. On the completion of his preparatory studies he entered the Escola Polytechnica, in Rio de Janeiro, but later transferred to the Escola de Minas, which had lately been established at Ouro Preto, and at which he graduated in 1880.

The School of Mines had been established by the Imperial Government of Brazil in 1875, at the famous old city of Ouro Preto, formerly known as Villa Rica. I can not do better than to quote from what I have said elsewhere of the institution:

João C. Costa Sena

"The establishment by the Imperial Government of the national Escola de Minas at Ouro Preto in 1875, and the opening of that school October 12, 1876, was a step of the greatest importance, not only for engineering education in Brazil, but also for the advancement of the science of geology in the State and throughout the whole country.. Some of Brazil's ablest engineers and, with but few exceptions, all of her geologists and mining engineers have been educated at that school." [1]

Its first director was the distinguished French geologist, Dr. Henri Gorceix, who held that position for sixteen years and started the school on its brilliant career. Immediately upon graduation young Sena was appointed instructor in mineralogy and geology in the School of Mines, and in 1885 he was made professor of physics and chemistry in the same institution, a position which he held until 1891. In that year, Doctor Gorceix retired as director of the school and Doctor Costa Sena succeeded him, and held that office until his death, in 1919.

In addition to his duties as professor and director of the School of Mines, Doctor Sena was a member of the Constitutional Assembly of the State of Minas, and from 1891 to 1902 he was a member of the State Senate. In 1898 he was elected Vice-President of the State of Minas for four years, and for some months he acted as governor of the State. In 1908-1909 he represented Brazil in the Pan-American Congress in Chile. He was a public-spirited citizen as well as a mineralogist and an educator.

His energies were devoted chiefly to the development of the School of Mines, and he succeeded in making it the most important institution for the study of geology, mineralogy, and mining engineering in that country. It thus came about that his contributions were in the field of educational administration rather than in scientific research, and it was in the School of Mines that he rendered his greatest service to his country and to science.

His published papers are not numerous and consist chiefly of notes upon the occurrence of minerals in the State of Minas Geraes. He was more familiar with the minerals of the region about Ouro Preto than any one else.

Dr. Eugen Hussak named the mineral *Senaite* in his honor.

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1. Noticia sobre a mineralogia e geologia de uma parte do Norte e Nordeste da Provincia de Minas Geraes. Annaes da Escola de Minas de Ouro Preto, 1883, no. 2, pages 111-131.
2. Note sur la scorodite des environs d'Ouro Preto. Bul. Soc. Minéral. de France, VII, 218-220. Paris, 1884.

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7. Note sur un gisement d'actonite aux environs d'Ouro Preto. Bul. Soc. Française de Minéral., XVII, 267-269. Paris, 1894.
8. Nota sobre uma jazida de staurotidas nas vizinhanças de Ouro Preto. Annaes da Escola de Minas, no. 5, 1902; also in the Revista Industrial, October 15, 1893.
9. Exposição Mineralogica e Metallurgica de Santiago de Chile. Annexo no. 7 do Relatorio Apresentado ao Dr. Presidente do Estado de Minas Geraes . . . em o anno de 1895, II, 43 pages, Ouro Preto, 1895. (Contains notes on Brazilian minerals, ores, and rocks.)
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12. Mineral resources of the State of Minas Geraes, Brazil. Mining and Metallurgy, XXIV, December 15, 1901, 703-705. New York, 1901.
13. Nota sobre uma jazida de actinote na fazenda do Barião etc. Annaes da Escola de Minas, no. 5, 1902.
14. Notas sobre a cassiterita no Norte de Minas, sobre a apatita e topazio provenientes dos arredores de Fortaleza e cidade de Salinas. Annaes da Escola de Minas no. 6, 1903.
15. The Tapera gold deposit. Brazilian Mining Review, May, 1904.
16. Nota sobre uma jazida de blenda no municipio de Ouro Preto, no lugar denominado Morro do Bule. Annaes da Escola de Minas, no. 8, 1906.
17. Memoria apresentada ao Congresso Scientifico Latino-Americano. Annaes de Escola de Minas, no. 10, 1908.
18. Minerios de ferro no Brasil, principalmente no Estado de Minas. Considerações geraes sobre a industria do ferro. Annaes da Escola de Minas de Ouro Preto, no. 10, 1908, pp. 19-34. Ouro Preto (n. d.).
19. Breve noticia sobre a columbita no Estado de Minas Geraes. Annaes da Escola de Minas, no. 11, 1909.
20. O bismutho em Minas Geraes. *Auri-Verde*, Ouro Preto, July, 1919, 4-5.

TITLES AND ABSTRACTS OF PAPERS PRESENTED BEFORE THE MORNING SESSION OF TUESDAY AND DISCUSSIONS THEREON

After the delivery of the memorial to Professor Iddings the scientific program was taken up and the remainder of the session devoted to the consideration of reports showing the progress of the work done by the Committee on Sedimentation of the Division of Geology and Geography

of the National Research Council during the past year. The papers were as follows:

GENERAL STATEMENT ON THE WORK OF THE COMMITTEE ON SEDIMENTATION, DIVISION OF GEOLOGY AND GEOGRAPHY, NATIONAL RESEARCH COUNCIL

BY T. WAYLAND VAUGHAN

(*Abstract*)

In opening the symposium on sedimentation it was stated that the present discussion was a continuation of the one held last year, before the meeting of the Society at Boston. As a development from the suggestions made at that time, the chairmen of several subcommittees were appointed and the present symposium consisted of the reports of these chairmen.

It was also stated that there were at least two defects in the present organization of the work of the committee, and that it has hoped these might soon be remedied. One of the defects is that there is not sufficiently close affiliation with those primarily engaged in the study of soils, and the other is that the relations are not so close as they should be with certain groups of geologists, whose major efforts are devoted to economic work.

The full reports of the subcommittees will form part of the report of the chairman of the Committee on Sedimentation to the chairman of the Division of Geology and Geography, National Research Council. Abstracts of the reports are presented here.

Presented in abstract from notes.

STUDIES OF SEDIMENTATION IN THE UNIVERSITIES OF THE EASTERN PART OF THE UNITED STATES

BY E. S. MOORE

(*Abstract*)

A survey of the colleges and universities east of the Alleghany Mountains shows that the problems of sedimentation have not been receiving the attention which they merit. It also shows that many institutions have not fully recovered from the disturbing influences of the war, but they are gradually taking up again those problems which are usually regarded as of more strictly scientific than utilitarian importance. An excellent spirit of cooperation with the National Research Council's work on sedimentation is manifested in replies to requests for information regarding work under way, and it is expected that the study of numerous problems in sedimentation will be undertaken during the coming year, partly on the initiative of men already interested in such problems and partly at the suggestion of the Committee on Sedimentation.

Read from manuscript.

STUDIES OF SEDIMENTATION IN THE UNIVERSITIES OF THE CENTRAL PART OF THE UNITED STATES

BY W. H. TWENHOFEL

(Abstract)

A part of the work which the Committee on Sedimentation of the National Research Council has outlined for itself is the stimulation and encouragement of investigation of problems relating to sediments and the development of courses in the universities in which emphasis would be placed on the study of sediments. Data as to the existing state of affairs were collected along two lines, namely, the teaching of courses in sedimentation, and research work directly related to problems of sedimentation.

Courses in sedimentation are given in two universities, Iowa and Wisconsin. The course in Wisconsin is the older. A course in the principles of sedimentation was given at Minnesota in 1918-1919, which appears to have been discontinued with the departure to another institution of the man who gave it.

Problems connected with sedimentation are being actively investigated in Iowa, North Dakota, Missouri, and Wisconsin universities and the Colorado School of Mines, while research in problems connected with sedimentation are being conducted in most of the other universities of the Mississippi Valley.

Read from manuscript.

STUDIES OF SEDIMENTATION IN THE UNIVERSITIES OF THE WESTERN PART OF THE UNITED STATES

BY G. D. LOUDERBACK

(Abstract)

A brief statement of recent research work on sediments and sedimentation, special courses offered in these subjects, work planned for the near future, and opportunities and suggestions for cooperation, as reported by universities in the western part of the United States.

Presented without notes.

Discussed by Messrs. T. W. Vaughan, George F. Kay, C. K. Wentworth, E. B. Branson, and A. C. Lawson.

SOME PROBLEMS OF SEDIMENTATION STUDIES SUGGESTED BY STATE GEOLOGISTS

BY JOHAN A. UDDEN

(Abstract)

The paper contains statements from a number of State geologists, suggesting various subjects which it is desirable should be investigated in the following States: Florida, Georgia, Illinois, Kentucky, Maryland, Michigan, Mississippi, North Dakota, Pennsylvania, South Carolina, Texas, West Virginia, and Wisconsin.

Dismissing in a few words the report set for presentation at this time, Doctor Udden presented the following paper, as being germane to the topic under discussion:

CHRONOLOGY IN GEOLOGY

BY J. A. UDDEN

It seems to me that one of the important aims in the study of sedimentation should be to attain more precise information on the relation between quantity of deposits and time represented. It has often been stated in discussions of geologic time that this is merely relative, and that the geologist can not be concerned with years, centuries, or millennia, as they are counted in history. Nevertheless, many attempts have been made at estimates of time expressed in years for all the sediments that have been measured, including even sediments of pre-Cambrian ages. Some such results have been regarded as rough estimates of the age of the earth since sedimentation began. They have mostly been based on two as yet largely unknown factors, the annual quantity of deposits brought down to the sea by the present rivers and the total thickness of all sediments, the calculation consisting in dividing the larger factor by the smaller. Lately it seems that some important observations have been made by the use of a more exact method, bearing on the duration of the postglacial deposits in the Baltic regions, and De Geer has been able to count in years the time elapsed since the glaciers disappeared in Sweden. Incidental to this work, he has shown that there is a great variety in the thickness of annual deposits of different kinds of material and at different points away from the source of the sediments. The annual layers of the finest silt farthest away are measured in millimeters, while the thickness of the annual layers of coarser sediments closer to the glacial source is measured in decimeters. In the proximal region of deposition the rate is somewhat like a hundred times greater than in the distal region.

Still more recently, in our own country, Robert W. Sayles has presented the results of studies on the banding of glacial clays in New England, and has secured evidence that seems conclusive of annual periodic variation in sedimentation in glacial clays along the Connecticut River. He makes reference, also, to other instances of banded clays that appear to be the result of seasonal variations in deposition.

Even if we considered that this work in correlating time with thickness of sediments has as yet been possible only in the special case of the latest sediments, it seems to me that there is reason to hope that a method of measuring time from the stratification of sediments may be found to have wide application.

We can, perhaps, never expect to be able to make out layers representing seasonal deposition in the greater part of the sediments of the past. Several circumstances make this impossible. In the first place, deposition has been interrupted. Our unconformities may represent as much time as our sediments. In the second place, there must be many shifts of an irregular nature in currents carrying sediments. These may entirely obliterate the annual variations consequent on seasonal rhythm. Then there is the important fact

to consider that in many places where sediments of the finest texture are laid down, there are animals and plants inhabiting the bottom of the sea, many of which obtain their nourishment from organic material contained in the slime and mud of the sea. Where deposition is slow, each annual layer, by the action of these living organisms, will become mingled with other layers in a homogeneous mass and can no more be measured separately than one scrambled egg can be separated from another.

But it does not appear at all unlikely that in the past, as well as at the present time, there are places where organisms only very slightly, or not at all, disturb the accumulating sediments. In glacial waters such undoubtedly has been the case, and this is the reason why lamination in glacial clays remains intact and trenchant. In most sedimentary rocks, especially in shales and clays throughout the whole geological column, we find that lamination is of frequent occurrence. We usually say that all sedimentary rocks are stratified. Almost all of these rocks show seams which must represent interruptions in deposition. These seams separate layers, ledges, or strata, which themselves represent time units of relatively uninterrupted deposition. The coarser sediments, on the whole, consist of thicker layers than do the finer sediments. Instances are not rare where we find considerable uniformity in the thickness of layers for certain formations or parts of a formation. Thus we speak of thin-bedded limestone and thick-bedded limestone; thin-bedded sandstone and thick-bedded sandstone. I think we have all noted the uniformity in bedding of certain limestones in the Pennsylvanian. The Carlinville limestone in Illinois almost everywhere, under sufficient weathering, exhibits a remarkable uniformity in this respect. It consists of layers measuring from two to four inches. Such regular bedding occurs in the Canyon limestone in central Texas and in the Permo-Carboniferous in west Texas. The separations between these layers are so minute that they do not always appear in outcrops which have not been considerably weathered. This bedding must represent some rhythm. I believe it is to be accounted for by some seasonal or other cyclic recurrence of a slight variation or interruption in the sedimentary process. In one case I have observed, in a vertical section of about fifteen feet, in the Comanchean sediments, a thrice-recurring cycle expressed in the repetition of three different calcareous layers clearly representing different conditions of deposition. Here there appeared to be seen the results of three smaller cycles within a larger cycle.

In looking over the literature containing detailed sections of strata, one is impressed with the fact that very few sections, as usually described, are sufficiently minute in detail to be taken as a basis for the study of any smaller cycles of sedimentation, such as may represent seasonal variations. The published literature contains very little that can be used for such studies as might throw light on either an annual rhythm or on any rhythm of commensurately longer cycles. Observations for the detection of any such phenomena must be carried to the minutest detail possible. We have here a *tabula rasa*. Our stratified rocks should be submitted to the minutest scrutiny for determining the smallest units into which their strata can be divided. Until a great mass of observations of this sort can be compiled and analyzed, it would be unwise to either affirm or deny the existence of evidence which may have a bearing on the measurement of actual time. To me the attempt to collect such data

seems worth while, even if the ultimate object in view should prove impossible to attain. Studies of this kind would, without doubt, result in learning much about sedimentation that we do not now know. The conditions under which sedimentation takes place have infinite variations. This much we can see from the great variety of sedimentary rocks showing innumerable differences, such as in texture of the clastic elements, in the size and composition of these elements, in their mingling and sorting, and in their lamination and bedding. These different characters, without any doubt, maintain certain relations to each other. What these relations are is a subject concerning which we have, as yet, very little information.

So far as I know, the only rhythms that have hitherto been noted in sedimentary deposits are the diurnal and the seasonal rhythms. There is at least one other cycle which may be found to appear in sediments. This is the twelve-year cycle of the sun-spot period. It seems to be fairly well established that precipitation in the United States is influenced by this cycle at the present time, and it may very well be that under certain general and world-wide climatic conditions the effect of this period may have been sufficiently marked to become apparent occasionally in sediments showing annual layers. Should such be the case, the appearance of this cycle would aid in identifying, and perhaps also in observing, the annual cycle. May there not also be other larger climatic cycles, such as cause variations that have been observed in the advances and recessions of our continental glaciers?

Everything considered, it seems correct to regard stratification in sediments as marks of time. The layers separating the ledges of limestone, so familiar in the quarry, are the most common features of stratified rocks. What do these signify? Is it likely that they are haphazard phenomena? I cannot believe that. A closer study of the details of stratification in sedimentary rocks, I believe, can not fail to give important results relating to more accurate estimates of geologic time, expressed in years. Even if we should be able to observe interpretable stratification only in scattered parts of the stratigraphic column, as seems most probable, we can expect that these will give us data invaluable to those who shall make a special study of time in geologic history.

Discussion

Prof. A. C. Lawson: It is necessary to discriminate carefully between apparent and real rhythm in sedimentation, in any effort to apply rhythm to the measure of geological time. The radiolarian cherts of the coast ranges of California afford a very fine example of apparent rhythm which is very probably not an expression of rhythm in the sedimentary process. The work of E. L. Davis, of the University of California, has shown that such an apparent rhythm may be produced in a beaker on the laboratory table.

CHEMICAL AND PHYSICAL RESEARCHES ON SEDIMENTATION

BY ROGER C. WELLS[1]

(*Abstract*)

The work of this subcommittee was carried on by conferences between the chairman and individual members of the committee. The information ac-

[1] Introduced by T. Wayland Vaughan.

quired shows that many chemical and physical researches have been made and are at present being made that have, or might have, a bearing on problems in sedimentation, but relatively few investigators are actually applying the results to geological processes or are making investigations of problems in sedimentation.

A list of titles of papers based on physical and chemical researches bearing on sedimentation has been prepared for papers that have appeared during the last year. The list shows several classes of investigations. Papers that describe sedimentary deposits in more or less detail are prominent. There are some papers that deal with methods of analysis and measurement. The behavior of colloids affords a voluminous literature, showing that this branch of science is growing and that theories are being tested and qualifying facts added to first generalization. There are also papers involving botany, soil, chemistry, the acidity and alkalinity of waters, flocculation, alteration of rocks, and dehydration.

Read from manuscript by E. W. Shaw.

FIELD DESCRIPTION OF SEDIMENTS

BY MARCUS I. GOLDMAN

(Abstract)

This is the report of a subcommittee of the Committee on Sedimentation of the National Research Council. The purpose of the work of this subcommittee, which consists of D. F. Hewett, Kirk Bryan, and Marcus I. Goldman, chairman, is to prepare a schedule that can be pasted in the cover of a notebook for use in the description of sediments and sedimentary rocks in the field. As it is impossible to include in such a schedule all the characters that might be recognized, the aim has been to list those which are more generally considered important or which are related to current trends of interest in the study of sedimentary rocks. The compilers have particularly emphasized the importance of stating the results in quantitative terms.

Presented from notes.

PREPARATION OF A TREATISE ON SEDIMENTATION

BY W. H. TWENHOFEL

(Abstract)

The treatise in course of preparation is designed to cover the range of processes and phenomena which have to do with the origin, transportation, deposition, and solidification of sediments. It is believed that such a work, besides furnishing a convenient summary of what is at present known regarding sedimentation and the criteria for interpreting sediments, may both stimulate and guide future researches.

Read from manuscript.

CANADIAN STUDIES IN SEDIMENTATION

BY E. M. KINDLE

Presented without notes.

At the conclusion of the reading of the foregoing reports the more general program was taken up, beginning with the presentation of a paper entitled

ASSOCIATION OF GLAUCONITE WITH UNCONFORMITIES[1]

BY MARCUS I. GOLDMAN

(Abstract)

The study of the so-called "Bend series" of Texas (Lower Pennsylvanian and Mississippian), both in outcrops and in well drillings, brings out clearly that the more pronounced changes in lithology are marked by a layer of autochthonous glauconite at the base of the overlying lithologic unit. Autochthonous glauconite is very little, or not at all, developed in other parts of this section. The glauconite is often associated with phosphate granules or concretions, generally with unusually abundant sulfide, with abundant shells or coarse fragments of shells, and with coarse sand. The clearest instances of this stratigraphic significance of glauconite are at the contact of the Mississippian and the Ordovician (Ellenburger limestone). In the latter stratigraphic position a coarse glauconite layer has been found at several points of the outcrop—in a well 120 miles to the north of the outcrop and in two wells in an intermediate position. The occurrence of phosphate at unconformities has previously been noted by Cayeux, and its association with glauconite was recognized. There is little doubt that glauconite, phosphate, and sulfide are all related to the occurrence of organic matter. Cayeux has pointed out that under present conditions phosphate associated with glauconite forms where warm surface currents meet cold, causing a destruction especially of plank tonic and nectonic animals; but this condition is too local to account for such widespread layers as are found. Cayeux has formulated the indicated condition in the more general term "rupture of (marine) equilibrium," producing changes of current, of depth, etcetera. It should not be assumed that it is the actual momentary change in the environmental conditions which causes most of the destruction of life, but its more permanent effect in bringing into contact mutually incompatible life environments. If the general fact of an unusual destruction of life at unconformities is accepted, it is significant for the paleontologist as a possible factor in producing the differences between successive paleontologic horizons.

Presented in full without notes.

Remarks on Doctor Goldman's paper were made by Doctors I. C. White and E. S. Moore.

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[1] Published with the permission of the Director of the U. S. Geological Survey.

At 12.30 o'clock the Society adjourned for luncheon, reconvening at 2.15 p. m. in two sections for the reading of papers. Under the chairmanship of Vice-President George P. Merrill the following papers were presented:

TITLES AND ABSTRACTS OF PAPERS PRESENTED BEFORE THE AFTERNOON SESSION AND DISCUSSIONS THEREON

SYNGENETIC ORIGIN OF CONCRETIONS IN SHALE

BY W. A. TARR

(*Abstract*)

Studies of calcareous and siliceous concretions occurring in shale in the Cretaceous in South Dakota, Wyoming, Montana, and in the Pennsylvanian in Missouri have led to the conclusion that these concretions were formed contemporaneously with the inclosing beds. The evidence supporting this view is as follows: the concretions lying along one bedding plane, the recurrence of bands of concretions at fairly regular intervals, the relationship of the concretions to the bedding planes, and certain features of the concretions themselves.

DISCUSSION

Dr. STEPHEN TABER: A few years ago I studied some calcareous concretions in shales near Union Springs, Cayuga County, New York. I was struck by the sympathy shown by many of the concretions with respect to a plane bisecting them parallel to the bedding. Where this sympathy is shown by concretions I think that it indicates their growth subsequent to the deposition of the overlying beds, for absence of material on top would make growth easier in that direction and subsequently result in unsymmetrical concretions.

Prof. G. H. CHADWICK: Concretions in the upper Devonian Portage shales of western New York are arranged in definite planes, as described by Professor Tarr, but among these are large ones, as figured long ago by James Hall in his report on the Geology of the Fourth District of New York, with cone-in-cone structures constituting the upper and under sides of the concretions. These suggest that the concretions have grown subsequently and exerted pressure against the inclosed strata.

Dr. SIDNEY POWERS: Concretions of impure limestone at the Butler salt dome, in Texas, described in the American Journal of Science, 1920, show replacement by iron carbonate which has caused the development of cone-in-cone structure. This structure distorts and destroys the fossils in the concretions. The concretions were evidently formed contemporaneously with sedimentation.

Prof. R. D. SALISBURY: Certain calcareous concretions in shale about which laminæ bend appear to be syngenetic. These concretions appear to have grown in a shale and to have bent laminæ up above themselves and down beneath. In these cases laminæ are greatly thinned above the highest part of the concretions and below the lowest, while at the sides of the concretion between the

bent laminæ there is evidence of a space filled in, the filling showing laminæ. Laminæ bent about a concretion hereby seem to prove syngenetic origin.

Prof. A. C. LAWSON: It is probable that in cases where cone-in-cone structure is confined to a particular bed of wide extent the structure is due to the escape of gas from decaying organic matter beneath the layer in question before its consolidation, when it was in a more or less viscous or pasty condition.

Dr. H. S. WASHINGTON: In connection with the formation of cone-in-cone structure, attention may be called to the occurrence of concentric thinning spherical shells (saucers) beneath bombs that had fallen in the tuffs of one of the volcanoes. Their origin may be assigned, somewhat doubtfully, to the pressure produced by the impact of the bomb.

Prof. W. A. TARR: Cone-in-cone occurs on the upper and more rarely on the lower side of the concretions which occur in the Mawry member of the Graneros shale. In view of the horizontal stratification lines in these concretions which are discontinuous with those around the concretions, it seems doubtful that the cone-in-cone was developed by pressure. Recent studies by the writer, as well as published views, raise the question of origin of the cone-in-cone. The old view, that they were due to pressure, may be questioned and the origin of cone-in-cone by crystallization be the actual case. In this particular case certainly the concretion was syngenetic and therefore the cone-in-cone not due to pressure.

Read from manuscript.

The paper was discussed by Messrs. Stephen Taber, G. H. Chadwick, W. H. Twenhofel, Sidney Powers, R. D. Salisbury, A. C. Lawson, W. H. Bucher, and H. S. Washington.

RAIN-DROP IMPRESSIONS AND MARKS OF SOMEWHAT SIMILAR APPEARANCE

BY W. H. TWENHOFEL

Read from manuscript.

DISCUSSION

Dr. H. S. WASHINGTON remarked on the globules of volcanic dust produced by rain descending through the eruption cloud of the 1790 explosive outbreak of Kilauea, Hawaii, and preserved in the ash.

Dr. E. O. HOVEY cited the similar abundant globules formed during the explosive eruption of Mount Pelé, Martinique, in 1902.

STRUCTURAL FEATURES OF INDIANA

BY STEPHEN VISHER[1]

(Abstract)

The outstanding structural features of Indiana may be enumerated under the following heads:

[1] Introduced by Ellsworth Huntington.

1. The Northern Basin.
2. The Southwestern Basin.
3. The Ordovician-Silurian Arch.
4. The Mississippian Rift Zone.

Northern Basin: Considering the Silurian as the floor of the basin, it is occupied by about 400 feet of Devonian, Mississippian, and Pleistocene deposits.

Southwestern Basin: Contains Devonian, Mississippian, Pennsylvanian, and Pleistocene rocks measuring a total thickness of 2,500 feet.

Ordovician-Silurian Arch: Separates the two basins; is a northward extension of the Cincinnati Arch; bedrock surface of the arch composed of Ordovician and Silurian strata, the former in the southeastern and the latter in the central and northwestern parts of the State.

Mississippian Rift Zone: Lies on the southwest side of the arch and roughly parallels it; in a general way follows the western border of the outcrop of the Knobstone (Keokuk) division of the Mississippian; is characterized by several structural features, namely, Mount Carmel Fault, Heltonville Fault, Denniston Anticlinal.

Mount Carmel Fault: Probably extends from the Ohio River northwestward to the Illinois-Indiana boundary; amount of throw, 300 feet; direction, east and north; evidence of two periods of movement.

Heltonville Fault: Minor displacement one mile west of the Mount Carmel Fault at Heltonville; parallel with the major fault; Warsaw faulted against Keokuk; may pass into the Mount Carmel Fault and into the Denniston Anticlinal Structure.

Denniston Anticlinal: Produced by downthrow of southwestward dipping strata toward the east and north; characterized by a short, steeply dipping limb toward the fault and a more gradual dip on the longer opposite limb.

Discussion

Prof. W. H. Hobbs: The glacial anticyclones to which Mr. Visher has referred must, during special glacial periods, be enormously increased in vigor. As I have already shown, such great fixed whirls in the atmosphere constitute an essential part of the circulatory system. They are windpoles of the earth, which gather in and pull down the upper currents of the atmosphere, bringing them to the surface and returning them equatorward. Any increase in their vigor will, therefore, accentuate the zonal contrast.

TUTUILA, SAMOA, AND THE CORAL REEF PROBLEM

BY ROLLIN T. CHAMBERLIN

(*Abstract*)

A description of the coral reefs of the island of Tutuila, American Samoa, and their bearing on the various theories which have been advanced in explanation of barrier reefs and atolls.

The island of Tutuila is bordered by a submerged shelf which has an average width of about two and one-half miles. Near the outer margin of this shelf is

an old barrier reef now lying beneath some thirty fathoms of water. Deeper water lies between it and the shore. The critical question is whether the barrier reef has been built up from the original sloping sides of the volcanic island by the accumulation of great thicknesses of coral material, or whether the coral structure is a much thinner veneering built on a wave-cut platform. Tutuila seems to declare in favor of the platform. Since the shelf was cut and the barrier reef formed, the island has subsided relative to the sea, drowning the corals of the old reefs. More recently still there has been a movement of the strand-line in the opposite direction, as evidenced by a bench ten feet above high tide on nearly all the promontories of the island. A fringing reef is now growing out from the shores just below present sealevel.

Presented without the use of notes.
Discussed by Dr. T. Wayland Vaughan.

SOME GEOLOGIC FEATURES OF THE BEARTOOTH MOUNTAINS, MONTANA

BY ARTHUR BEVAN [1]

(*Abstract*)

This paper is a preliminary report on the salient geologic features of the Beartooth Mountains, which form the front range of the Rocky Mountains in southern Montana and northwestern Wyoming. The most striking physiographic features are (1) the abrupt rise of the range from the Great Plains at an elevation of approximately 6,000 feet to an even rim at about 9,000 to 9,500 feet; (2) a moderately dissected sub-summit plateau several miles wide, that extends nearly the full length of the range; and (3) distinct remnants of a summit plateau at an elevation of about 12,400 feet. Granite Peak, which, at 12,850 feet, is the highest mountain in Montana, has a nearly flat summit that probably is a similar remnant.

Nearly all the valleys on the plainsward slope have been severely glaciated during at least two distinct epochs. An extensive ice-cap occupied a considerable portion of the western slope, from which several lobes passed across the axial divide and down the valleys to the bordering plains on the east. The rocks of the range consist of a pre-Cambrian crystalline core which is surrounded by an apparently conformable series of sedimentaries that range in age from the Middle Cambrian to the early Eocene (Fort Union). The Silurian system only is absent. The columnar sections for northern Wyoming and southern Montana can be harmonized in this range, as the formations of both areas meet along its eastern base.

The range is structurally an asymmetric anticline that is overturned toward the plains. It is bounded along nearly the entire eastern front by the Beartooth fault, which is a profound overthrust. This fault is probably the northward extension of the Heart Mountain overthrust of northwestern Wyoming. Other faults, about which little is yet known, are present along the western base of the range.

Read from manuscript.

[1] Introduced by R. T. Chamberlin.

EVOLUTION OF ARCUATE MOUNTAINS

BY W. H. HOBBS

(*Abstract*)

Following Suess, it has been a general practice to regard the folds within mountain arcs as overthrust outward from within the arc. In 1912 the writer, in a series of three papers which appeared in the Journal of Geology, showed that the mechanics of the folding process in rocks requires that the folds be underthrust from without inward, and that this is borne out by the character of the deformation within the folded strata.

Since the arcs are convex toward the oceans, this requires that the active force which produced the folding be exerted from the sea toward the land—not from the land area toward the surrounding seas. The study is here extended to a consideration of the relationship of each mountain range to the sea on the border of which it was pushed up. Many of the serious difficulties which Suess encountered in attempting to fit his theory to observed facts when regarding the seaward slide of the land-masses now disappear completely. The problem is further greatly simplified for the reason that we can delimit the areas covered by former seas through mapping their deposits, whereas former land-masses have often left little trace of their existence beyond the mass of their migrated deposits.

Presented without manuscript.

Discussion

Prof. A. C. Lawson: I am glad that Mr. Hobbs is pursuing his studies of the origin of arcuate mountains. I am inclined to agree with him that underthrusting is far more common than overthrusting. The important thing for geology, from a general point of view, is the cause of this underthrusting or the force which operates to produce it. According to Mr. Hobbs, this cause is to be found, in the case of the arcuate mountains of Asia, in the collapse of the Pacific arc and the consequent thrust from the deepening oceanic basin toward the continent. I do not believe that this is the cause. Even if the Pacific arc were to collapse, as suggested, the force could not be propagated for such long distances. The crust would be sheared infinitely before the effect of the thrust could be felt in Asia. We must recognize another force applied to the under side of the crust, a subcrustal current which carries the crust with it, creating strains which find expression in the arcuate mountains. What, then, is the cause of this subcrustal current? It is to be found in the application of the principle of isostasy. If a continental region is subjected to erosion, the load is transferred seaward. Compensation is effected by a subcrustal flow from the region of loading to the region of degradation. This current carries the crust with it, and the newly deposited sediments are folded when they are crowded against the passive region toward which the current is flowing. This process is repeated from age to age, giving us the sequence of arcuate mountains from north to south, growing seaward by underthrust from the early Paleozoic to the late Tertiary.

Prof. B. Willis: The mechanics of overthrusting and underthrusting are determined by local conditions, among which the relative vertical positions of active pressure and passive resistance are most influential. If the line of pressure be directed above the resistance, we have overthrust. If the pressure be directed under the resistance, we have underthrust. In general, I dissent from the author's conclusions as to the relative position of pressure and resistance in the cases cited by him. What he calls pressure I would call resistance, and *vice versa*.

Dr. Stephen Taber: Professor Hobbs has referred to the destruction of bridges during earthquakes because of the approach of their abutments as proof of the crustal shortening of the earth. I have examined quite a number of bridges damaged and destroyed by earthquakes. In all cases when there was an approach of the abutments, it could be explained as the result of the slumping of superficial material on which the abutments had been built. Abutments built on solid rock are not permanently displaced toward one another, although the bridge trusses sometimes hammer against the stones in the abutments until the rock is pulverized. Evidence of slumping is often furnished by the formation, farther back, of cracks running parallel to the streams.

Prof. W. H. Hobbs: I have elsewhere shown how the drawing together of the piers of bridges is usually on loose soil and explained it by a localization of the slipping of the loose formations over the hard rocks. The fissuring along river banks is a practically uniform observation in regions affected by earthquakes, but it does not indicate tension. It is purely a result of shocks which throw off layers of earth of the banks, just as the last of a series of boys in line is thrown off when the line is pushed.

SOME POINTS IN THE MECHANICS OF ARCUATE AND LOBATE MOUNTAIN STRUCTURES

BY FRANK BURSLEY TAYLOR

(Abstract)

Following the suggestion of Suess, a comparison is made of the patterns of marginal moraines of continental ice-sheets and the marginal chains of Tertiary fold-mountains marking the southern periphery of the Eurasian continental crust sheet. Certain similarities of arcuate and lobate forms seen in the marginal structures of both ice and crustal sheets are very striking, and it is pointed out that, in spite of the wide differences in the general characteristics, composition, and physical properties of ice and rock, these closely similar marginal forms and their relations to the sheets of which they form marginal parts prove that both ice and rock sheets move in conformity to the same law, and that they behave alike when they find unobstructed channels of easy flow. The arcs and lobes of the Tertiary peripheral mountain ranges of Eurasia, especially in the interval between the Philippines and Gibraltar, exhibit a striking uniformity of strength and intensity or development along the whole interval, and in general, wherever there is exceptional development, either in greater or less strength than the average, there is an evident reason for it. This means general southward crustal movement toward the folded margin.

Certain geologists have laid a criticism against Suess, claiming that his mechanics of the production of the mountain arcs is at fault, in that the crustal material from which Suess derives the fold-mountains of a given arc are supposed to have moved outward from the relatively small area within the arc, moving from a center toward three sides. This point is discussed in the paper, and it is made clear, in Suess's own words, that this is not his conception of the mechanics of the mountain arcs. The mechanics of mountain arcs and lobes, under Suess's interpretation of these forms, is set forth briefly and the dependence of these ideas on Suess's broader views of crustal movements on continental scales is discussed. A number of examples of particular mountain forms which strongly support Suess's interpretation are considered in their bearing on the general problem of the origin of the earth's principal features.

Presented by title in the absence of the author.

DOCTRINE OF THE ZONE OF FLOW CHALLENGED

BY W. H. HOBBS

(Abstract)

The idea of a zone of flow within the lithosphere, a doctrine which was developed by Van Hise, requires for the process of rock folding that the strata involved shall support a load which is equal to or greater than their crushing strength. This doctrine seems to have been generally accepted by geologists, though correction of the figures for crushing strength have been made so as to apply to hydrostatic conditions and have carried the depth of the upper limit of the zone of flow to several times that which was estimated by Van Hise.

When this doctrine is applied to the explanation of an angular unconformity, vertical displacements of strata become necessary which have magnitudes great enough to carry the interpretation perilously close to an absurdity. Reasons are given for believing that the element of time has not been given sufficient weight in reaching the conclusions, and recent work in the Pacific is cited to show that folds are today actually taking place at and above the present level of the sea.

Presented without manuscript.

CRUSTAL DEFORMATION IN THE PACIFIC AND ATLANTIC REGIONS

BY W. H. HOBBS

(Abstract)

The recent study of earthquakes from remote stations has proven conclusively that the larger movements of the earth's crust which are now going on have taken place near, though largely inside, the borders of the Pacific Ocean, though there is a strong subordinate zone which follows the twin plane of the intercontinental seas, thus conforming quite closely in direction with the floors of deposition for the Mesozoic era. Outside these zones the lithosphere surface may be described by contrast as in repose. The contrasted conditions for the Atlantic and Pacific regions are therefore striking.

The process of marine degradation which shapes the continental shelf, and in case of rapid uplift yields coast terraces, supplies us with a measure for the rate of crustal deformation. Wherever uplift goes on slowly, as it does about the margins of the Atlantic, the treads of the coast terraces are found to be both broad and elaborately eroded by stream action and the average angle of the terraces is small. Cuestas may be developed. Wherever, on the contrary, uplift is going on rapidly, as it is on the borders of the Pacific area, the treads of coast terraces are narrow and the risers relatively high, the surface of the treads is smooth and but slightly affected by river erosion, and the average angle of the terrace series will be correspondingly large.

Presented by title at the request of the author.

OROGENIC FORCES

BY HARRY FIELDING REID

(Abstract)

Normal faults can not be formed by tension. Vertical forces are necessary, and in general, when the dip is high, horizontal pressure must exist.

The forces elevating mountain ranges must be distinguished from the horizontal forces causing folding. It can be shown that many of our present mountain ranges owe their elevation to vertical forces.

Read by E. B. Mathews in the absence of the author.

AN OBJECTION TO THE CONTRACTION HYPOTHESIS AS ACCOUNTING FOR MOUNTAINS

BY FRANK BURSLEY TAYLOR

(Abstract)

Under the law of cooling for a molten globe which would cool at a progressively diminishing rate, and of contraction which would also follow cooling at a progressively diminishing rate, folding of the earth's crust and mountain-making would go on at a doubly or compounded diminishing rate. The amount of crustal shortening needed to account for the Tertiary mountain belt would require a great accumulation of crustal stresses over a very long time. But the rocks of the crust show clearly by fold-mountains that they are incompetent to sustain such accumulations. Huronian tillite in Canada indicates a relatively cold state, like the present, as existing at that early time, so that the amount of cooling in the two or three geological ages preceding the Tertiary can not have been as great as in the ages preceding the Huronian. It is to be considered, further, that several mountain-making periods since the Huronian have probably relieved most of the stresses produced in that time, so that the required amount of accumulation for the Tertiary mountain belt was impossible.

The Tertiary mountain belt shows a world-wide cause which can only be ascribed to an astronomical force. A capture theory for the origin of satellites was proposed some years ago by two or three different authors. A newly cap-

tured satellite, especially if it were a relatively large one, would make an immediate change in the equilibrium of the globe. It would set up new stresses of world-wide character and would increase the degree of oblateness of the earth's figure. In order to explain displaced strand-lines, Suess postulates a recent change of the figure of the sea from a less degree to a greater degree of oblateness. The same force would act on the solid globe and set up new stresses in it. The unity of the Tertiary mountain belt, extending around the whole earth, requires a cause beginning with relative suddenness and with powerful world-wide action and to continue for a long time. The capture of a large satellite about at the beginning of the Tertiary would explain the facts as no other hypothesis yet suggested can.

Presented by title in the absence of the author.

AN ORIGIN OF CRYSTALLINE SCHISTS

BY CHARLES R. KEYES

(Abstract)

Concerning the genesis of the crystalline schists, it is commonly regarded that it is the direct result of intense compression, aided by new chemical reactions and recrystallization along closely parallel lines. On a small scale the same foliation takes place along shear planes. For the larger scale, where great mountain ranges and cordilleras are involved, there seems to be another interpretation. A belt of sedimentary or igneous rocks simply sinks down into the zone of rock flowage. On its return to sky it comes back schist.

The central *massif* of the southern Rocky Mountains appears to reflect clearly such conditions. No less than four times since the close of the Paleozoic era do the present surface rocks of the area seem to have been depressed into the zone of rock flowage. As in the Piedmont Plateau of the Middle Atlantic slope the old Paleozoics and pre-Cambrian sediments are changed over into massive schists. But these schists, instead of being the most ancient rocks of which we have knowledge, as was not so very long ago believed, are in all probability post-Paleozoic in date of formation.

Presented by title in the absence of the author.

SECTIONAL MEETING

The section which met at 2.10 o'clock, Tuesday afternoon, for the consideration of stratigraphic and related topics, convened in Rosenwald Hall, under the chairmanship of President I. C. White, with R. S. Bassler serving as secretary. The first paper on the program was

DEVONIAN OF MINNESOTA

BY CLINTON R. STAUFFER

(Abstract)

About 1,200 square miles of southern Minnesota are known to be covered by Devonian deposits. Limestone boulders carrying a similar Devonian fauna

are occasionally found over a large area in the south central part of the State and indicate that there may be Devonian outliers beneath the drift covering at some distance from what appears to be the main body of the deposit.

The Minnesota Devonian consists chiefly of limestone, much of which is abundantly fossiliferous. It probably all belongs in the formation known in Iowa as the Cedar Valley limestone.

Read from manuscript.

Discussion was postponed till after the reading of the next paper, entitled

DEVONIAN OF MISSOURI

BY E. B. BRANSON

(Abstract)

The Devonian of northern Missouri contains the following formations: Cooper limestone, Minneola limestone, Calloway limestone, Snyder Creek shale. The Cooper and Minneola are Middle Devonian in age. The fauna of the Minneola resembles that of the Jeffersonville limestone of Indiana and the Grand Tower of southeastern Missouri. It also contains several species common to the Devonian of Iowa. The Cooper and Minneola seas were in part contemporaneous, but the Cooper sea withdrew before the close of Minneola time, and the Minneola spread so as to overlap part of the Cooper. The western boundary of the Minneola sea was about 20 miles east of Columbia, Missouri, and the southern boundary stretched from north of Saint Louis to the Missouri north of Columbia.

Presented without manuscript.

These two papers were discussed by Messrs. E. M. Kindle, A. F. Foerste, A. O. Thomas, David White, R. C. Moore, C. R. Stauffer, D. W. O'Hern, I. C. White, and E. B. Branson.

SOME STRUCTURAL FEATURES OF INDIANA

BY W. N. LOGAN

Presented without notes.

Doctor Logan's paper was discussed by Messrs. G. H. Chadwick, D. W. O'Hern, Stuart Weller, and J. H. Bretz.

NICHOLASVILLE (KENTUCKY) WELL

BY ARTHUR M. MILLER

(Abstract)

A well drilled for oil one-quarter of a mile south of Nicholasville, Kentucky, by a Winchester (Kentucky) oil company was abandoned last summer at a depth of 3,200 feet. Located on the summit of the "Jessamine Dome" of the Cincinnati anticline, at this depth it constitutes the deepest well geologically

drilled in the Ohio River basin. Starting near the base of the Lexington (Trenton) limestone, it disclosed the following stratigraphic succession:

Formations	Thicknesses Feet
Trenton limestone (Hermitage and Curdsville)	40
Tyrone limestone	80
Oregon and Camp Nelson limestone	430
Knox dolomite	2,880
Nolichucky shale and sandstone	320
Total	3,200

The shale brought up in the sand pump from the bottom has been identified by E. O. Ulrich as Cambrian by the presence in it of fragments of certain Cambrian trilobites.

In locating this well on the top of the Jessamine Dome, below any known productive oil horizon in the eastern United States, the drilling company disregarded the advice of geologists and pinned their hopeful expectations to the findings of a forked peach tree switch in the hands of one of its members.

The paper was accompanied by an exhibit of the drill cuttings arranged in order in a glass tube to the scale 1½ inches equal 100 feet.

Presented without manuscript, with sample section of well.

Discussed by Messrs. A. F. Foerste, M. Y. Williams, R. M. Bagg, and I. C. White.

President White withdrew, after calling Prof. A. M. Miller to the chair.

STRATIGRAPHIC PROBLEMS IN THE COLUMBIA VALLEY BETWEEN SNAKE RIVER AND WILLAMETTE RIVER

BY J. HARLEN BRETZ

(*Abstract*)

The dominant formation of this part of the Columbia Valley is a great series of basalt flows, a part of the immense basalt field of eastern Washington and Oregon. Direct tracing up the canyons tributary to the Columbia shows that what has long been assumed is undoubtedly correct, this series of flows is the same as that named Columbia River basalt by Merriam in the upper John Day Valley of north-central Oregon, and Yakima basalt by G. O. Smith in Yakima Valley of south-central Washington.

The Satson formation, as earlier defined, is a widespread fluviatile deposit extending along the Columbia Valley from the mouth up through the Columbia Gorge section of the Cascade Range and as far east as Yakima Valley. In the gorge and eastward, the Satson formation rests unconformably on the Columbia River basalt. Exposures of this fluviatile deposit are not continuous and fossils are very rare. Correlation of separate outcrops is based on lithologic characters and stratigraphic and topographic relations. It is believed, however, to be the record of one epoch of stream deposition, of Pliocene or early Quaternary age.

The Dalles beds, in Oregon, immediately east of the Cascade Range, are thought to be made up of two different formations, the lower of which is a phase of the Satson formation and the upper a post-formation deposit of volcanic ejectmenta of local origin and small extent.

A sedimentary deposit about Arlington, Oregon, and Roosevelt, Washington, 50 miles east of the Dalles, is believed to be an eastward continuation of the lower part of the Dalles beds and to represent the Satson formation. It has yielded vertebrate remains.

Another sedimentary deposit in this locality is probably correlative with the Mascall and Ellensburg formations, of Miocene age.

Two drainage courses of the Satson epoch are thought to be traceable westward to a confluence near Lyle, Washington, on the eastern slope of the Cascade Range. One is followed now by Columbia River for about 100 miles above the Dalles, the other crosses several anticlinal uplifts between Lyle and Priest Rapids, 90 miles to the northeast, and lies at right angles to the course of Yakima Valley.

There are only three post-deformation water-laid deposits in the valley above the present floodplain: (1) the upper part of the Dalles beds; (2) gravel terraces whose grade rises about two and a half feet per mile from the Portland delta (altitude, 300 feet above tide) eastward for at least 150 miles, and (3) berg-borne erratic material throughout the full length of the valley here discussed (upper limit, about 1,250 feet). All are of Pleistocene age, 1 being the oldest. The relative ages of 2 and 3 are not yet known.

Presented without notes, with lantern-slide illustration.

EVIDENCES OF AN UNCONFORMITY WITHIN THE PRE-CAMBRIAN OF THE BLACK HILLS OF SOUTH DAKOTA

BY J. J. RUNNER[1]

(Abstract)

Field studies in the northeastern portion of the pre-Cambrian area of the Black Hills of South Dakota have furnished evidences of the existence of a hitherto unknown unconformity that separates the pre-Cambrian of that region into two divisions of the probable rank of systems. The older system of sediments outcrops within an oval area approximately three miles by two miles in extent and occupies the center of a slightly elongated domical structure. The intrusion of igneous rock into both systems is thought to have had an effect in producing the structure. Large masses were intruded near the center of the dome and along the western flank, where there appears to be a large fault.

The older formation comprises quartzites, quartz-sericite schist, and iron formations consisting of alternate bands of quartz and specular hematite or magnetite. Completely surrounding this older system is a younger one, composed of conglomerates, quartzites, iron formations, limestones, and various schists and slates. The contact between the two is, in places, clearly an erosional one. The basal member of the younger system is generally a conglom-

[1] Introduced by George F. Kay.

erate, containing in places huge boulders of precisely the same character of rock that is found in the older only a few feet distant, and at some of these points the older beds are clearly truncated. In other places the contact is obscure, while in still others it is quite clearly a fault contact.

The existence of boulders within the conglomerate containing drag folds and brecciated structures; of firmly cemented quartzite pebbles within a chloritic matrix; and the considerable angle between the bedding planes of the two systems is evidence of the time represented in the unconformity.

The younger iron formations are regarded as of fragmental origin, derived from the older. The banding of the younger at least is believed to have been produced during metamorphism rather than by original sedimentation. Furthermore, the banding is more pronounced in the formations richer in iron.

The pre-Cambrian of the remainder of the hills area probably belongs to the younger system. In degree of metamorphism the two systems resemble the Huronians of the Lake Superior district.

Presented without manuscript, with the aid of charts.

STRATIGRAPHY AND DIASTROPHISM OF WESTERN NEWFOUNDLAND

BY CHARLES SCHUCHERT AND CARL O. DUNBAR

(*Abstract*)

Paleozoic sediments form a low foreland to the Long Range Mountains along the entire western coast of Newfoundland. The stratigraphic sequence begins with a well developed Lower Cambrian, resting on Laurentian granite and metamorphics, and closes with the Pennsylvanian. There is here no Middle Cambrian nor Silurian; of the Devonian, only the Helderbergian is present, and of the Mississippian only the latter half. All of Mesozoic and Cenozoic time is entirely unrepresented by sediments. The Lower Cambrian consists of quartzite, shale, and limestone, and its fauna shows limited relations with that of eastern Newfoundland, whereas all the succeeding faunas indicate complete isolation of these two regions. The Upper Cambrian is poorly represented by dark gray, shaly limestone, which is accordant with both the preceding Cambrian and the succeeding Ordovician strata.

The Ordovician is here tremendously developed. It begins with about 2,000 feet of dolomite and magnesian limestone of Canadian age, followed by some 800 feet of purer Chazyan limestone, and then, as orogeny set in to the east, there was a gradual transition into black shaly limestone, black shale, and finally into a great greenish gray sandstone. On this follows, after a break in sedimentation, the Cow Head limestone breccia, locally of great thickness and of unparalleled coarseness—a product of landslides resulting from profound fault-scarps near by. As the orogeny continued to its climax, there followed a mighty series of clastic sediments, possibly more than 10,000 feet in thickness and very variable in both color and texture from section to section. These clastics have yielded but very few fossils, apparently of Middle Ordovician time. After this the seas cleared somewhat and Ordovician sedimentation closed with fossiliferous shales and limestone referred to the later Ordovician, ending with the earlier Richmondian.

The Lower Devonian (Helderbergian) sediments are red and green clastics with extensive ripple-marks, mud-cracks, and salt hoppers, and with marine fossils confined to limited zones. The later Devonian was a second period of orogeny, marked by folding and by both extrusions and extensive laccolithic intrusions of very basic lavas.

Deposition did not begin again until the Upper Mississippian, when there was laid down the more or less marine Windsor series of red and variegated clastics, with local dolomite and gypsum having limited occurrences of marine fossils. The Pennsylvanian sediments are wholly of continental origin and contain some coal locally. A third period of orogeny was that of the Appalachian revolution, which began here some time late in the Paleozoic.

The next deposits are Pleistocene tillites, derived from the east, and these are locally overlain by fossiliferous marine clays of late Pleistocene time, which in places are as high as 100 feet above present sealevel.

Little is recorded in Newfoundland of its Mesozoic and Cenozoic history, though the island was reduced to peneplanation, after which, probably in late Cenozoic time, there was an uplift, greater in the west than in the east, which brought the flat-topped Long Range to its present elevation of about 2,000 feet.

Presented by title in the absence of the authors.

STRATIGRAPHY OF THE MOOSE AND ALBANY RIVERS OF NORTHERN ONTARIO

BY M. Y. WILLIAMS

(*Abstract*)

The rock exposures of these river courses indicate a geological section interpreted in age as follows: Queenston, Cataract?, Niagara, Guelph, Salina, early Upper Devonian (formerly classed as Arondaga), Tully, Huron, and Portage. Mesozoic sediments are represented in the Mattagami basin by clay shales, lignites, and plant-bearing sandstone. The Pleistocene section includes boulder till, outwash sands and gravels, marine clay and sand, and what is believed to be interglacial peat. The beds for the most part dip toward James Bay at the rate of about two feet per mile, but marked open folds occur in the Moose River basin, where thin sheets and narrow dikes of trap cut the early Upper Devonian limestones.

Presented without notes, with charts and lantern slides.

AGE OF THE ANDES

BY EDWARD W. BERRY AND JOSEPH T. SINGEWALD, JR.

(*Abstract*)

Evidence is brought forward, from scattered localities extending from Colombia and Venezuela on the north to Patagonia on the south, showing that marine Pliocene is involved in the last and greatest uplift of the Andes. It is shown by means of fossil plants that Amazon basin conditions formerly prevailed along the present west coast. The probability of the existence of a

land area west of the present coast is discussed. From a consideration of several different Pliocene floras from Bolivia, an approximate estimate is given of the amount of uplift that has taken place since the Pliocene. Paleontologic and topographic evidence is presented showing that a moderate Tertiary elevation was followed by rather mature erosion, and this in turn by profound elevation, which was accompanied by great igneous and volcanic activity, the latter almost entirely confined to the western ranges. The bulk of the mineralization also dates from this time, especially in the eastern ranges of Bolivia, in which region this conclusion has been demonstrated.

Presented by title in the absence of the authors.

PRE-CAMBRIAN ROCKS OF MANITOBA

BY F. J. ALCOCK AND E. L. BRUCE

Printed in full in this volume.

OCCURRENCE OF BASAL CONGLOMERATES

BY W. H. TWENHOFEL AND E. C. EDWARDS

(*Abstract*)

In many textbooks of geology the initial deposits over an unconformity are represented as conglomerates or coarse sandstones, and the impression is left that such are the general accompaniment of an unconformity. Observations made on many geologic sections show that such is not always the case, and that the initial deposits in many cases are fine clastics, while coarser clastics are altogether wanting or occur some distance above the initial strata. It appears to have been the custom to refer the occurrence, where no coarse clastics are present, to the invasion of the sea over a peneplaned surface, or that a coast had been eroded of which the materials could not produce coarse clastics.

Observations made on many parts of the coast about the Gulf of Saint Lawrence have led to the conclusion that gravels and coarse sands are not necessarily the initial deposits of an invading sea, even under conditions of considerable relief, and that it is equally as probable that the initial deposits above an unconformity should be fine clastics.

Presented in abstract by the senior author from notes.
Discussed by M. Y. Williams, with reply by W. H. Twenhofel.

LLANORIA—THE PALEOZOIC LAND AREA IN LOUISIANA AND EASTERN TEXAS

BY HUGH D. MISER

(*Abstract*)

Evidence for a Paleozoic land area that occupied at least a part of Louisiana and eastern Texas has been published from time to time by different geologists. The most important paper on the subject is one by J. C. Branner, published in the American Journal of Science in 1897. Considerable informa-

tion on the subject was obtained by the late Dr. A. H. Purdue and the writer during several years' study of the rock formations in the Ouachita Mountains and Arkansas Valley of Arkansas and Oklahoma, beginning in 1907. The following conclusions are based on this information and on the data published by other geologists.

A land area, which has been called Llano by Willis, Schuchert, and Ulrich and Llanoria by Dumble, existed in Louisiana and eastern Texas during much, if not most, of the Paleozoic era and during the Triassic and Jurassic periods of the Mesozoic era. It varied in outline from time to time. It may have occupied a part of the area of the present Gulf of Mexico; at times it was doubtless connected with large land areas occupying at least much of central and northern Texas, southern Oklahoma, and southern Arkansas, and for short periods it may have extended eastward across the lower Mississippi Valley and joined the southwest end of the Appalachian area. It furnished most of the sediments that formed the clastic rocks of Pennsylvanian age in north-central Texas, and for those of Ordovician, Silurian, Mississippian, and Pennsylvanian age in the Ouachita Mountains and Arkansas Valley of Arkansas and Oklahoma. At times, as during the Devonian period, it had very little relief, but at other times, as during the Ordovician and Silurian periods and the Mississippian and Pennsylvanian epochs, it was mountainous. It was depressed and entirely submerged during Lower Cretaceous time, and later depressions carried the sea across it during Upper Cretaceous, Tertiary, and Quaternary time, so that its rocks are now covered and entirely concealed by deposits of these ages. The discovery of pre-Cambrian schists directly beneath Cretaceous strata at Waco, Georgetown, Maxwell, San Antonio, and Leon Springs, Texas, suggests that the rocks of this old buried land area were similar to the crystalline rocks now exposed in the Piedmont Plateau of the eastern United States. If so, such rocks underlie the Cretaceous strata over much of Louisiana, eastern Texas, and perhaps adjoining areas to the south and east. Prominent structural features of the Gulf Coastal Plain, including the Preston anticline and Sabine uplift, may mark the location of some of the folds that were produced in the rocks on the old land area, but that have undergone further movement since they were buried by Cretaceous and later sediments.

The results of future deep drilling in the Gulf Coastal Plain and further study of the Paleozoic and older rocks that are exposed around the borders of the Gulf Plain will add greatly to our imperfect knowledge of the old land area considered in this abstract.

Read from manuscript, illustrated with charts.

Discussed by Messrs. R. C. Moore, E. H. Sellards, G. H. Chadwick, and E. S. Bastin, with replies by the author.

IGNEOUS GEOLOGY OF SOUTHEASTERN IDAHO

BY GEORGE ROGERS MANSFIELD

Presented by title in the absence of the author. This paper is printed in full in this volume.

The section adjourned at 6 o'clock p. m.

Session of Tuesday Evening

The Society and its friends convened at 8 o'clock p. m. of Tuesday, December 28, in the Auditorium of Rosenwald Hall, to listen to the presidential address, entitled

IMPORTANT EPOCHS IN THE HISTORY OF PETROLEUM AND NATURAL GAS

PRESIDENTIAL ADDRESS BY I. C. WHITE

This paper is published in full in this volume of the Bulletin.

Doctor White's address was followed by that of the retiring Vice-President of Section E of the American Association for the Advancement of Science, which is entitled

STRUCTURAL FAILURE OF THE LITHOSPHERE

BY C. K. LEITH

ANNUAL SMOKER

After the reading of these papers the Society adjourned to one of the laboratories in the same building, where was held the annual subscription smoker. This function was likewise participated in by the members of the Paleontological Society, the Mineralogical Society of America, the Society of Economic Geologists, and guests of all the societies. The attendance was large and the function enjoyable.

Session of Wednesday Morning, December 29

The Society came together for its second general session at 9.45 o'clock a. m. of Wednesday, December 29, with President I. C. White in the chair. The first business on the docket was the report of the Auditing Committee, elected on the previous day. This was presented as follows:

REPORT OF THE AUDITING COMMITTEE

Chicago, *December* 28, 1920.

To the Geological Society of America:

The Auditing Committee have examined the records of the Treasurer for the calendar year 1920 and find the Treasurer's statement as printed to be correct. We recommend its approval, subject to the checking of the securities in Baltimore by Dr. J. T. Singewald, Jr.[1] [See note on opposite page.]

(Signed) Edson S. Bastin,
Frederick B. Peck,
Joseph T. Singewald, Jr.,
Auditing Committee.

On motion, the printed Council report was then taken from the table and considered. It was voted that the report be accepted and printed in the Bulletin.

AFFILIATION WITH THE SOCIETY OF ECONOMIC GEOLOGISTS

The Secretary then announced that the Council on December 28, 1920, had received overtures from the Council of the newly organized Society of Economic Geologists looking toward close affiliation with the Geological Society of America, on which favorable action had been taken. The following letter has been received since and the Secretary has been instructed to submit it to the Society for action:

CHICAGO UNIVERSITY, *December* 28, 1920.

DR. E. O. HOVEY,
Secretary, Geological Society of America.

DEAR DR. HOVEY: The Society of Economic Geologists, at its organization meeting this afternoon, unanimously adopted a resolution directing the Secretary to apply for affiliation with the Geological Society of America under the provision of the newly adopted amendment to its Constitution. In compliance with these instructions, I take pleasure in transmitting this application to the Geological Society of America through you, in anticipation of mutually helpful relations in the years to come.

Very sincerely yours,
(Signed) J. VOLNEY LEWIS,
Secretary, Society of Economic Geologists.

On motion, duly seconded, the Society unanimously approved the acceptance of the Society of Economic Geologists as an affiliated society and directed the Secretary to transmit notice of its action.[2]

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[1] Since the meeting the following letter has been received by the Secretary:

BALTIMORE, MARYLAND, *January* 20, 1921.

As a member of the Auditing Committee for 1920, I have examined the securities of the Geological Society of America in the safe-deposit box in Baltimore and find them as reported by the Treasurer at the annual meeting.

(Signed) JOSEPH T. SINGEWALD, JR.

[2] Carrying out these instructions, the Secretary dispatched the following letter to the Secretary of the new organization:

CHICAGO, ILLINOIS, *December* 29, 1920.

Prof. J. VOLNEY LEWIS,
Secretary, Society of Economic Geologists.

DEAR PROFESSOR LEWIS: Acknowledging the receipt of the application of the Society of Economic Geologists for affiliation with the Geological Society of America under the latter Society's Constitution and By-Laws, I have the honor to report that said application was submitted to the Geological Society of America in general session this morning and was unanimously approved, a most hearty welcome being extended to the new society.

Very truly yours,
(Signed) EDMUND OTIS HOVEY,
Secretary, Geological Society of America.

TITLES AND ABSTRACTS OF PAPERS PRESENTED AT THE MORNING SESSION AND DISCUSSIONS THEREON

The Society then took up consideration of papers of general interest with the presentation of

GEOLOGY AND GEOGRAPHY IN THE UNITED STATES

BY EDWARD B. MATHEWS AND HOMER P. LITTLE

(*Abstract*)

An exhaustive report on the status of geology and geography, prepared for the Division of Educational Relations of the National Research Council. The report is based on an extensive study of the personal history and publications of 2,500 men and women interested in the subjects named and a more intensive study of over 1,200. The points considered are the present personnel and its training, the opportunities offered for training in geology and geography, publications dealing with North American geology, organizations supporting research, and the lines of investigation now in progress.

In reply to a question by Prof. W. W. Atwood, Doctor Mathews said that only one institution in the country was thoroughly equipped for training of geographers. The demand for trained geographers far exceeds the supply, and initial salaries are good.

Read from manuscript by the senior author.

PRE-CAMBRIAN PROBLEMS

BY J. J. SEDERHOLM [1]

(*Abstract*)

Historical development of the study of the pre-Cambrian of northern Europe. Older ideas. Explanation by actual causes.

Petrological problems:

1. Primary constitution of the rocks of the pre-Cambrian.
2. Their metamorphism.
3. Their anatexis.

Stratigraphical problems:

Present state of our knowledge of the stratigraphy of the pre-Cambrian of Fenno-Scandia.

Correlation with rocks in other countries.

Geotectonical problems:

Do the great granitic masses possess any definite age?

Orogenetic zones in the pre-Cambrian of Fenno-Scandia.

Presented by title in the absence of the author.

[1] By invitation of the Council.

MOBILITY OF THE COAST RANGES OF CALIFORNIA

BY ANDREW C. LAWSON

(*Abstract*)

The paper adduces evidence that the region is moving northerly by strain creep, due to a subcrustal current. This strain is relieved from time to time by faulting and the region springs back, causing an earthquake at each slip. The displacements of 1868 and 1906, as determined by the U. S. Coast and Geodetic Survey, may be explained consistently with this conception. The rebound of 1868 was an expression of relief from longitudinal strain effected by a deep lowly inclined fault with a strike normal to the direction of stress. The rebound of 1906 was a relief from transverse strain on a vertical fault oblique to the direction of stress.

Read from manuscript.

CERTAIN MARKED DIFFERENTIAL MOVEMENTS IN THE SAN FRANCISCO BAY REGION

BY GEORGE D. LOUDERBACK

(*Abstract*)

Brief statement of physiographic contrasts of east and west sides of San Francisco Bay. Evidence of general movements and of differential movements based on consideration of physiographic features, alluvial deposits, and bay deposits, present and former cross-sections of a drowned valley, borings, and core samples of bottom deposits. Brief comparison of recent diastrophic relations of this region with those of Tertiary time.

Presented without notes.

Discussion

Prof. W. H. Hobbs: I am glad that Professor Louderback's paper has been read in connection with Professor Lawson's, for I think that supplies an alternative, and I believe a truer picture of the type of deformation which took place during the earthquake of 1906. I believe it only fair to say that the Reid theory of that earthquake, indorsed as it is by Lawson, grows out from the notion that the California earthquake was unique, instead of being not essentially different in its nature from others. No attempt was made to fit the Reid theory of strain creep and rebound to other earthquakes. I consider it fair criticism of the studies made by the geologists who studied the earthquake that they made no adequate survey of the vast field of seismological knowledge already at hand, but, on the contrary, started out as though their own observations were alone of importance.

Professor Lawson replied that the first volume of the report on the California earthquake of 1906 sought merely to lay the facts of that quake before the scientific public, and that the second volume brought out the application of a theory that, as far as known, had not theretofore been applied to earthquakes.

VOTE OF WELCOME TO PROF. T. C. CHAMBERLIN

President White then said: "I have the pleasure of announcing one of the nestors of our science, our beloved former President, Prof. T. C. Chamberlin, and I propose a rising vote of welcome." This was enthusiastically given by the audience, who then listened to the presentation of two papers, as follows:

THE GREATER EARTH

BY T. C. CHAMBERLIN

GROUNDWORK OF THE EARTH'S DIASTROPHISM

BY T. C. CHAMBERLIN

These two papers are printed in full in this volume.

Adjournment for luncheon was taken at 12.30 o'clock.

SESSION OF WEDNESDAY AFTERNOON, DECEMBER 29

The Society reconvened at 2.15 o'clock, with President I. C. White in the chair and H. L. Fairchild acting as Secretary.

TITLES AND ABSTRACTS OF PAPERS PRESENTED AT THE AFTERNOON SESSION AND DISCUSSIONS THEREON

The first paper presented was entitled

SOLITARIO UPLIFT, PRESIDIO-BREWSTER COUNTIES, TEXAS

BY SIDNEY POWERS

(*Abstract*)

Intensely folded Lower Paleozoic rocks are exposed in only two uplifts in Texas, the Marathon and the Solitario Domes, both on the edge of the Cordilleran Mountain chains. In both the Marathon and Solitario areas the highly folded Paleozoic rocks are exposed in unroofed Cretaceous domes and the strike of the isoclinal folds is northeast-southwest. This shows that the folding is Appalachian, not Cordilleran, but the connection with the Ouachita, Arbuckle, or Wichita Mountains is not clear.

The Solitario consists of a perfectly circular rim of Lower Cretaceous limestones 7 miles in diameter, rising as jagged saw-tooth peaks and dipping outward at angles of 30 degrees to 70 degrees, within which are lower hills composed of Ordovician shales (Marathon and Maravillas formations), Devonian (?) Novacolite (Caballos), Pennsylvanian shales and sandstones (Tesnus formation), and limestones (Dimple formations). In the center of the unroofed Cretaceous dome a portion of the original Cretaceous cover is left,

unconformably overlying all the older formations. The south half of the dome is composed of volcanic breccia cut by many dikes. Blocks of the former Cretaceous rock have sunk into the breccia.

The origin of the Cretaceous dome, one of the most perfect in the world, is believed to be a laccolithic intrusion into the basal Paleozoic rocks. The breccia is believed to fill a pipe through which the laccolith broke and reached the surface at about the close of the Upper Cretaceous period. A sill in the basal Cretaceous can be traced completely around the dome.

Read from manuscript.

GREAT FAULT TROUGHS OF THE ANTILLES

BY STEPHEN TABER

(*Abstract*)

A series of fault zones extending along arcs that run approximately east and west have determined the major relief features in the region of the Greater Antilles. Displacements along these fault zones have resulted in the formation of great trough-like valleys. The fault troughs are for the most part submerged beneath the Atlantic Ocean and Caribbean Sea and are, therefore, protected from erosion. They are characterized by great depth, precipitous inclosing scarps, abrupt changes in slope at the top and bottom, and relatively flat floors that, instead of being graded like river valleys, rise and fall throughout their length. The deepest places are close to the foot of the inclosing scarps rather than near the center of the trench, while horsts are also present along the fault zones.

Practically all of the severe earthquakes which have occurred in this region during the last four centuries have originated along these fault zones, and they have been caused by vertical displacements, as is shown by the sea waves which have accompanied them.

Presented without notes.

The paper was discussed by Dr. T. Wayland Vaughan, Dr. I. C. White, and Prof. W. H. Hobbs, with reply by the author.

Discussion

Prof. W. H. Hobbs: I have taken great satisfaction in listening to this excellent paper of Professor Taber, for the reason that in common with that of Professor Louderback, read at the morning session, it indicates entire correspondence with the views which I have long held concerning the nature of block faultings, namely, that adjustments within any region are comparable to those which occur when floating blocks are disturbed by water waves. Troughs due to faulting do not begin and end gradually, as long supposed, but are interrupted *suddenly*. The interruption of the Bartlett Deep by the island of Haiti and the continuation of a depression to the northward of that island; the cross-trough of the Anegada Passage, all require this interpretation and this only. The smaller adjustment within the larger earth blocks have also been well established by Doctor Taber.

HERCYNIAN OROGENIC MOVEMENTS IN SOUTHERN OKLAHOMA

BY R. C. MOORE

(Abstract)

The Glenn formation, consisting of shales, limestones, and more or less asphaltic sandstones, is exposed on the south side of the Arbuckle Mountains of southern Oklahoma. Recent studies show that it is 10,000 to 15,000 feet in thickness, and that it is Lower Pennsylvanian in age. It is steeply folded and is concordant in structure with the older strata exposed in the Arbuckle Mountains. North of the Arbuckles are folded and tilted Lower Pennsylvanian rocks comprising the formations from the Wapanucka to the Wewoka, 10,000 feet in thickness, which are also concordant in structure with the older beds of the mountains. The beveled, peneplaned Lower Pennsylvanian is overlain by the Franks conglomerate, in which, from interbedded limestones, an Upper Pennsylvanian fauna has been found. The Franks has been traced northward and found equivalent to the Seminole conglomerate which rests on the Wewoka formation. An important unconformity which appears to correspond to the break in sedimentation in the Arbuckle region has been recognized and traced across the north Texas-Pennsylvanian area. It occurs near the base of the Cisco group.

The movement which produced the Arbuckle Mountains may be correlated with the Hercynian disturbance in mid-Pennsylvanian time. It exerted a very important influence on the structure, sedimentation, and faunas of the Pennsylvanian in the Mid-Continent region.

Read from manuscript.

FRAMEWORK OF THE EARTH

BY PETER MC KELLAR

Read in abstract from manuscript.

ORIGIN AND DISTRIBUTION OF THE LOESS

BY G. FREDERICK WRIGHT

(Abstract)

I

1. Analysis of typical loess in the Missouri Valley shows that it is the product of mechanical disintegration rather than of chemical. It is composed mostly of angular crystalline particles, among which are feldspar, hornblende, oxides of iron, and tourmaline. This could not have come from the Mississippi Valley west of the Missouri River. It is evidently the product of the mechanical erosion of the continental glacier over the granitic areas of Canada and the Lake Superior region.

2. Reexamination of the specimens of Chinese loess collected by Pumpelly fifty years ago probably points to a similar origin from the glaciated area of

Tibet. But we suspend judgment on this point until fresh specimens arrive, which are promised.

II

The loess is almost everywhere distributed around the margin of glaciated areas where it would be naturally brought by the floods of the waning ice-sheets.

1. This is clearly shown in the publication of the twenty-sixth volume of the Iowa Geological Survey, where it appears that while the area occupied by the Wisconsin ice lobe is free from loess, it is accumulated over sharply defined areas to the east, to the south, and to the west. Such a distribution could not have been produced by the prevailing winds.

2. My own observations indicate a similar relation to glaciated areas both in Europe and in Asia. The southern plains of Russia are covered with loess related to the advance of the great Scandinavian ice-sheet very much as those of Iowa are to the Wisconsin ice-sheet. This I had noted especially at Kiev, on the Dnieper, and at Rostov, on the Don. In Asia the evidence is specially convincing at Samarkand, where the Zerafshan debouches from the Ali Tagh mountain range, which still supports glaciers, and at Tashkent, where the Chircik and the Keles, branches of the Syrdaria, come down from the north-western projection of the Ala-tau range. The Chinese deposits are, on the original theory of Pumpelly, similarly related to the glaciated area of Tibet.

3. Extensive and minute studies, by Miss Luella A. Owen, of the snail shells distributed through the loess at Saint Joseph, Missouri, show that they are species of snail which delight in moisture and are favored by a cold climate. Moreover, these species are still living in the small streams at the base of the loess cliffs at Saint Joseph.

4. The distribution of the loess in these localities by water is made conceivable and reasonable by the facts which have accumulated, which indicate enormous floods during the closing stages of the Glacial epoch and also extensive variations in land levels connected with the period.

Presented by title in the absence of the author.

VALLEY GRAVELS OF NORTHWESTERN IOWA [1]

BY JAMES H. LEES

(Abstract)

An extension and continuation of studies on gravel deposits of Crawford County, Iowa, begun by the writer ten years ago. These gravels were originally thought to be Aftonian, but showed no features supporting such a hypothesis, and the writer reached the conclusion that they were Buchanan or Yarmouth or later. More recently Carman has studied these gravels in connection with his studies on the Pleistocene Geology of northwestern Iowa, and has discussed them in Iowa Geological Survey, volume XXVI, pages 380-414. The present study extends the investigation farther south and east than was

[1] Printed with permission of the State Geologist.

included in Carman's territory or in the area originally examined by the writer. The gravels in this original area were found in valleys cut in Kansan drift, and so belong in the same series as Carman's Valley gravels, which he defined as being "those gravels which occupy valleys in the Kansan area that could not have been reached by outwash from the Wisconsin ice-sheet, and which are, therefore, not Wisconsin gravels." This definition has been adhered to in the present study, although it may be added that, even in the case of valleys which could have been and probably were reached by Wisconsin flood-waters, the true valley gravels, according to the above definition, are distinguishable by being overlain by loess.

It is a characteristic of northwest Iowa that the Kansan till is fresh nearly or quite to its surface, in contrast with the Kansan till of southern Iowa, which is leached for several feet below its upper surface. This characteristic seems to imply that the upper leached portion of the till was eroded prior to the deposition of the loess. It is probable that the valley gravels owe their origin to this erosive process, which was concomitant with a differential uplift of this part of the State.

Every stream valley heading within this area of fresh till, so far as these have been examined, contains valley gravels. These are in great part overlain by loess or a loess-like clay. The same is true also of valleys in west-central Iowa which head south of the area which was so distinctly affected by sheet erosion as to have all its leached till removed. The west margin of the Wisconsin drift-sheet is close to the Mississippi-Missouri divide in this region, so that few streams in the Kansan area drain eastward. However, one such valley was examined and was found to contain abundant valley gravels. Nearly all the streams of northwestern Iowa flow southeast or southwest, but at least one northward flowing stream is bordered by valley gravels as abundantly as are those streams flowing in the normal directions.

As to the date of their formation, these gravels are, of course, pre-Peorian, since they are overlain by loess which is recognized at present as being of Peorian age. How much older they may be is uncertain. As they are unleached and unweathered and are in places interleaved with loess, they would seem to be but little older, though this can not be positively affirmed. They are doubtless derived chiefly from the Kansan till. They must be differentiated from the so-called Aftonian gravels, which in the type localities Kay has shown to be really included masses of gravel rather than interglacial horizon markers. They are also distinct from the gravel hills and masses of northwestern Iowa, which Carman showed were likewise included within the Kansan till. These included masses must have contributed largely to the valley gravels. The valley gravels lie indiscriminately on Kansan or Nebraskan till and are found at different heights above the streams, ranging from water level to fully eighty feet.

Read from manuscript.

Discussed by Prof. J. A. Udden, George F. Kay, and J. Ernest Carman, with replies by the author.

GLACIAL SECTION AT CALGARY, ALBERTA

BY EDWARD M. BURWASH

(*Abstract*)

1. General physiographic description of the locality.
2. Relation of Glacial deposits in the physiographic development and location of section studies.
3. Description of section:
   (*a*) Lower till.
   (*b*) Interglacial sediments.
   (*c*) Upper till.
4. Comparison with coast section.
5. General inferences.

Read by title at the request of the author.

President White withdrew, after calling Vice-President A. C. Lawson to the chair.

A LATE PLEISTOCENE READVANCE OF THE ICE-SHEETS IN THE VANCOUVER REGION, BRITISH COLUMBIA

BY W. A. JOHNSTON

(*Abstract*)

Investigation during the past summer in the Vancouver region, British Columbia, has shown that a marine horizon occurs in the Pleistocene deposits at various places and at various heights up to 250 feet above sealevel. The marine deposits are overlain in places by till and in other places by outwash deposits and stratified silt and clay. They are younger than a till which overlies the Admiralty sediments and Admiralty till, as referred to by E. M. Burwash. The field evidence and probable significance of the occurrence is briefly discussed.

Read from manuscript.

The paper was discussed by Prof. George F. Kay, Dr. J. Harlen Bretz, and Dr. E. M. Burwash, with replies by the author.

DISCUSSION

DR. J. HARLEN BRETZ: A shell-bearing clay, associated with sand and gravel, lies between two till sheets in the northern part of Whatcom County, Washington, not more than twenty miles south of the international boundary. These till sheets lie above the Admiralty sediments, and apparently record two advances of the Vashon ice-sheet over northern Whatcom County and the presence of the sea there during the interval between these two episodes. A marginal moraine, one of the most prominent in the glaciated area of western Washington, lies just south of the region of the shelly clay between till sheets. It apparently is the record of the southernmost limit reached by this readvance of the Vashon ice.

Dr. E. M. Burwash: I was interested in Mr. Johnston's new evidence as to a mirror ice readvance at the close of the Vashon time. Two of his sections have been excavated since my fieldwork was done. The third, near White Rock, I did not see. Apart from the data now adduced by Mr. Johnston, there is further evidence for mirror ice readvanced on the Vancouver Island side of the Gulf of Georgia. At Departure Bay a section examined by me in 1908 showed a lower till sheet overlain by well laminated clay which had been planed off above by erosion. Above this were two, if not three, thin till sheets separated by somewhat irregular water-laid deposits of sandy or gravelly type, probably outwash in "some cases." [1]

SEDIMENTATION IN THE RECENT DELTA OF FRASER RIVER, BRITISH COLUMBIA, CANADA

BY W. A. JOHNSTON

(*Abstract*)

A study was made during parts of 1919 and 1920 of the characteristics of the lower part of Fraser River, British Columbia, and its delta. The investigation included observations of currents, determinations of the amount and character of sediment transported by the river, observations of water density and temperature, character of river bottom and subaqueous delta materials, and changes in the conditions of the river.

The results of the investigation were briefly given, with particular reference to the character and mode of deposition of the sediments as influenced by the various currents and by the interaction of river water and sea-water.

Read from manuscript.

NOTES ON THE KENNECOTT GLACIER, ALASKA

BY ALAN M. BATEMAN

(*Abstract*)

The gathering grounds of the Kennecott glacier are in the Wrangel Mountains, Alaska, at an elevation of over 16,000 feet. The glacier extends to an elevation of 1,800 feet, where it has a width of five miles. Its rate of movement at the margin and in the center was measured over a period of 374 days and the data are presented. Disconnected observations are made in regard to crevasses, disposition of morainal material, formation of esker-like lateral moraines, subglacial streams, and apparent glacial overriding with coarse till, now being deposited on top of finer water-sorted materials.

Presented without notes.

Discussion

Prof. R. T. Chamberlin: I have been greatly interested in this welcome paper on a glacier which has afforded such an excellent opportunity for the

[1] See "Contributions to Canadian Biology, 1906-1910," quoting a paper by Lamplugh in Geological Society, Edinburgh, which describes marine shells in the till excavated at Esquimalt dry-dock.

study of glacier motion. But I wish to emphasize the fact that its slow rate of movement may be the result of local conditions, and that, as Doctor Bateman says, further study on the glaciers nearer the coast should be made before it is safe to generalize for the region as a whole.

Dr. A. O. HAYES: I measured the rate of flow of the Bromley glacier, situated in the Portland Canal district, in British Columbia, about ten miles south of the Alaskan boundary. As the results have not been published and may be of interest in the discussion, I shall give the data from memory.

Two observations were made—the first in September, 1910; the second one year later. The average rate of flow was about one foot per day. The glacier flows from a large ice-field 6,000 feet and higher above sealevel, and extends down a valley about one mile wide for 6 miles, until at an elevation of 1,000 feet the end glacial stream forms the headwaters of Bitter Creek, a northerly flowing tributary of Bear River. Heavy tripods and lined in by a transit were placed across the glacier, one mile from its lower end and 1,000 feet apart. The midstream tripods moved down about 400 feet and those nearer the shores a less distance, with total variation of about 100 feet. The end of the glacier has retreated about 50 feet.

POSTGLACIAL CHANGES OF LEVEL IN NEWFOUNDLAND AND LABRADOR

BY REGINALD A. DALY

(*Abstract*)

Suspecting serious error in his 1900 measurement of the amount of postglacial emergence at Saint Johns, Newfoundland, the writer visited the island during the past season. He has found that the zero isobase for postglacial emergence crosses Newfoundland from a point on the west coast about forty miles north of Port-aux-Basques to a point on the east coast between Cape Bonavista and Fogo Island. The amount of emergence increases northward, measuring about 400 feet at Cape Bauld, Belle Isle Strait, and 540 feet at Forteau, Labrador. These figures for the north agree well with the determinations made in 1900. The 1900 measurement for Signal Hill, Saint Johns, was completely in error. Saint Johns is rather in a belt of submergence.

Presented by title in the absence of the author.

ACCORDANT LEVELS IN THE WHITE MOUNTAINS

BY ALFRED C. LANE

(*Abstract*)

The high level "lawns" like Boott Spur, studied by Goldthwait, may represent the top of the ice-sheet for a time prolonged, but not that of maximum glaciation. The Cretaceous baselevel seems to have been lower, about 2,635 feet above tide. The New England peneplain has been rightly followed by Lobeck, but is, as Barrell has suggested, a plain of marine denudation, and the plain about 1,100 feet above tide has in many places overtaken the higher terraces described by Barrell.

Presented by title in the absence of the author.

FIGURE 1.—Crest of Niagara Escarpment

PREGLACIAL SLOPE AND CREST OF THE NIAGARA ESCARPMENT

BY J. W. SPENCER

In the construction of the Welland Ship Canal at Thorold, Ontario, beneath 20 to 50 feet of sandy clay (laminated), the ancient rock surface has been exposed on the slope and face of the Niagara escarpment. Almost everywhere the clay rests directly on heavy bedded Niagara limestone—smoothed, polished and grooved—but in one depression was preserved a small mass of stony till, a scanty evidence of an earlier glacial deposit.

FIGURE 2.—*Rock Face of Niagara Escarpment*

The rock was exposed in constructing the ship canal at Thorold, Ontario. The glacier moved at right angles to the rock face.

There had been no further erosion of either the harder or softer strata than the truncation, smoothing, and grooving of their edges, as the glaciers of all the epochs were pushing up the slope of the escarpment (which now rises to 330 feet above Lake Ontario), in direction some 10 degrees west of south, the general course of the escarpment being nearly east and west. The two later and fainter sets of striations trend southwestward. Here was seen the most perfect example of weak effects of glacial erosion in the lake region.

In my original contribution on the origin of the lake basins being due to preglacial valleys, published under the inspiration of Prof. J. P. Lesley, the obliquity of the glaciation was one of the lines of evidence which I then set forth, but here we have also the more direct proof of the absence of any real work performed. The photographs were taken just before the crest was blasted away, in October, 1919.

FIGURE 3.—*Face of lower Ledge of Niagara Escarpment*

The rounded and grooved edge is produced by the glacier moving across it.

PENEPLAINAL AFFINITIES OF HIGH PLATEAUX OF UTAH

BY CHARLES R. KEYES

(Abstract)

Prodigious outpourings of lavas over the Cordilleran region of weste America during Tertiary times give origin at later date to curious landsca idiosyncrasies. Physiographically, mesa land is almost unique. Nowhere e on the face of the globe are there so many planation levels persisting in su close juxtaposition. Nowhere else are so many distinct plains presented c above another through a mile of air above the present general plains surfa or in old sediments through a space of several miles below the same surfa Nowhere else are climatic conditions so favorable for general plains genes From the very beginning of each geographic cycle, plain is the characterisi and dominant landscape type. Plateau plain of the desert is the reminisce record of intracycle planation such as is preserved in no other attainment baselevel.

Of the four great peneplains which spread over the ancestral Rockies sin the close of Paleozoic times, the Mid-Tertiary or Miocene savanna seems be represented in the last lingering traces by the summital flats of the hi plateaux. When these few all but vanquished remnants, the high plateaux Utah and the Mesa de Maya of the eastern side of the Cordillera, fina wither away, as they will shortly, no positive evidences of this once v peneplain remain. In the high plateaux of Utah lies also the key to the gene and structure of the Great Basin ranges.

Presented by title in the absence of the author.

SHORELINE MIGRATION AND RECENT COORDINATE CHANGES IN BOTTOM TOPOGRAPHY AT POINT PELEE, LAKE ERIE

BY E. M. KINDLE

(*Abstract*)

Slides were shown illustrating the physical feature of Point Pelee, which was described as a V-shaped foreland, about nine miles in length, chiefly marsh bordered by narrow bands of sand. The nature of the changes which the shoreline of the point has undergone since 1889 was indicated in a composite map showing on the same scale the seven surveys of the point which have been made previous to 1918. Two very detailed surveys of the shoreline of the southern portion of the point made by the Department of Public Works engineers in the years 1918 and 1920 were shown on one sheet, together with the lake bottom contours down to a depth of 25 feet, on a 5-foot interval. These two surveys were made in years when the lake stood at nearly the same level, thus eliminating the high and low water factor in modifying the outline of the shore. These surveys showed a southward extension of the narrow tip of the point during the two years represented, amounting to 1,175 feet. During the same period a considerable portion of the east shore showed some erosion, which near the residence of the captain of the life-saving crew reached a maximum amounting to about 100 feet. The southerly portion of the west shore showed a corresponding growth.

The two sets of soundings showed that great changes in the bottom topography had occurred during the two-year period included by them. On the west side, near the tip of the point, the contours showed a maximum westward movement of more than 300 feet. On the east side of the point the 20-foot contour has moved eastward in places 500 to 600 feet. In general the bottom on both sides of the point showed a more gentle gradient in 1920 than in 1918.

Presented without manuscript.

EXPERIMENTS ON THE FORMATION OF ESKERS AND KAMES

BY HERDMAN F. CLELAND AND PARIS B. STOCKDALE

(*Abstract*)

The apparatus used in these experiments are described and the preliminary results will be presented. Suggestions and criticisms of the methods and results are desired, in order that the authors may benefit by them in the further experiments on the formation of these glacial deposits.

Presented by title in the absence of the authors.

Adjournment was taken at 5.15 o'clock.

Sectional Meeting, Wednesday Afternoon

A sectional meeting for the consideration of petrologic, mineralogic, and economic papers met in one of the recitation rooms in Rosenwald

Hall at 3.40 o'clock, Wednesday afternoon, under the chairmanship of Vice-President Willet G. Miller, with Edmund Otis Hovey serving as secretary. The first paper read was entitled

A SIGNIFICANT PETROGRAPHIC UNCONFORMITY

BY CHARLES P. BERKEY

(*Abstract*)

Just as in the field of stratigraphy great reversals of the regular course of sedimentary development are indicated by misfit structures, so also is it in the field of petrology; but the nature of the evidence differs greatly and the method of investigating and the interpretation criteria belong by common consent to a branch of the science not usually credited with historical bearing. Some of these reversals in rock development and transformation are not recorded at all in stratigraphic form.

It is possible also that the paleopetrologist, or the man who reads the ancient history of rocks, may add to the understanding of the significance of the ordinary unconformities.

Read from manuscript.

ROCKS OF KOHALA AND KEA, HAWAII

BY HENRY S. WASHINGTON

(*Abstract*)

The Kohala Mountains, at the northern end of Hawaii, are the ruins of the oldest of the five volcanoes on the island. So far, the lavas of this center have been but little studied. The present paper is based on material collected in September, 1920.

The lavas of Kohala, for the most part, belong to two types of andesine basalt or oligoclase andesite, the hawaiite and kohalaite of Iddings. One is densely aphanitic and aphyric, and the other porphyritic, with many phenocrysts of plagioclase. The new analyses made indicate that, while at Kohala there is little difference between them, yet the lavas of this volcano, on the whole, are distinctly more alkalic than those of the recent volcanoes, Mauna Loa and Kilauea.

The study of the lavas of Mauna Kea is based chiefly on material from the lower slopes, especially from the lowest flows exposed in ravines along the coast, and not heretofore collected or studied, supplemented by Daly's study of lavas from the upper parts of the volcano. The lavas mostly fall into two types similar to those of Kohala and are similar chemically; they do not support Daly's suggestion of gravitative control at this volcano. A recent lava at sealevel has a composition almost identical with one collected by him from the summit. The analyses show that there is comparatively little difference in composition throughout. The paper is preliminary to a more general study of the lavas of Hawaii and the other islands of the group, based on recent collections made by the author and others.

Presented without manuscript.

MICROSCOPIC SECTIONS OF TILL AND STRATIFIED CLAY

BY ROBERT W. SAYLES

To grind microscopic sections of tillite and slate is a simple matter, but to obtain good sections of till and stratified clay in which the grains have not been disturbed since deposition is more difficult. For a long time I have been especially desirous of having thin sections of till and clay to compare with sections of tillite and slate. Heretofore the only method of comparing seasonally deposited slate layers with similar clay layers has been by taking small amounts of material from the coarse and fine parts of the yearly components and examining the grain under a microscope. Of the actual structure of the rock particles and their attitudes in the layers, nothing could be known except what could be seen with a low-power glass. Berkey was able to study the layers in the Grantsburg clays in this manner and obtain very important results, for this deposit lent itself to this crude method.

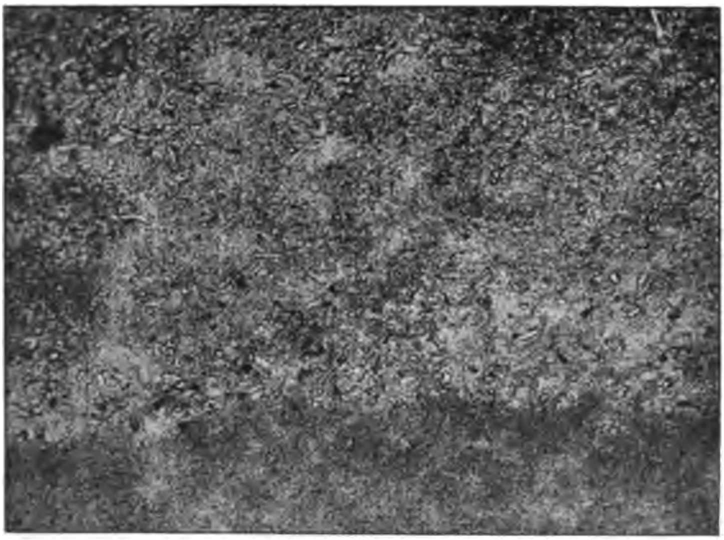

FIGURE 1.—*Section of Clay, Woodsville, New Hampshire*

After many attempts and failures to obtain a satisfactory microscopic section last year, I sought the advice of my friend and colleague, Prof. E. C. Jeffrey, of the Botanical Department of Harvard University. Through his help, after several unsuccessful experiments, a method was devised by means of which sections have been ground without disturbing the grains, although it has been impossible to avoid altogether cracks in the coarser clays.

The method of preparing the till or clay specimens for grinding is as follows: The material must be perfectly dried in a warm bath from seventy to one hundred degrees centigrade. Cool and drop into chloroform in a wide-mouthed bottle. Exhaust air to the extent of one atmosphere by high vacuum air pump used for several hours, so as to bring about complete penetration of

the chloroform. Leave over night in a tightly stoppered bottle, in a warm bath at a temperature of about fifty degrees centigrade. For a number of successive days gradually add powdered Canada balsam, from which all the turpentine has previously been driven by heat. This process should be continued for a week, and when the balsam has become as concentrated as possible, at a temperature of sixty or seventy degrees centigrade, the bottle is then immersed in a bath of water at the boiling point, so as to drive off all the chloroform. This will take a day or two. Finally the material is kept in a bath of glycerine (in the bottles, of course), kept at such a temperature as to keep the balsam melted and slightly bubbling. A very low Bunsen flame is enough, since the glycerine stores up heat and readily overheats and burns the balsam—a result to be avoided. About ten hours in the glycerine bath are enough. The pieces are then pulled out of the fluid balsam and allowed to cool, when they are ready for grinding.

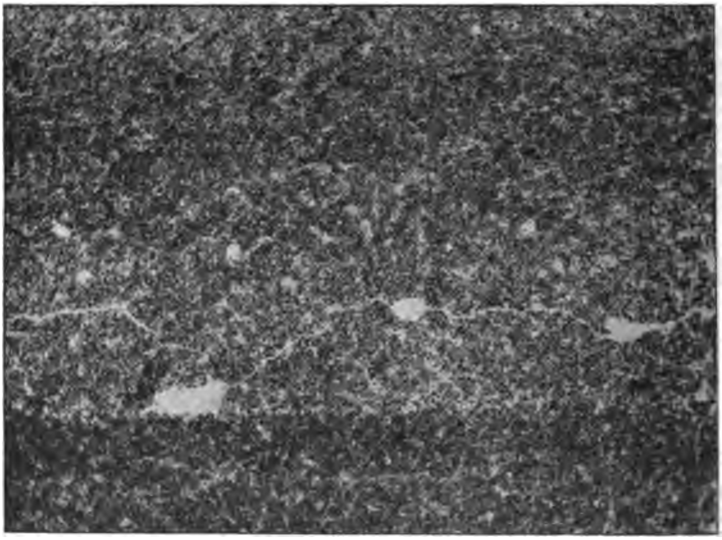

FIGURE 2.—*Section of Clay, Woodsville, New Hampshire*

To grind specimens of unconsolidated fine material prepared in this way, considerable care must be taken, when the desired thinness is approached, not to disrupt the section. They are not quite as firm as rock specimens. With care and patience good sections may be made by one used to grinding rock sections, although a novice might fail. Another difficulty is in avoiding grinding marks. Such difficulties as these, however, should not discourage any one, for many good sections have already been made with a minimum of practice.

Cut number 1 is a section of seasonally deposited clay from Woodsville, New Hampshire. The top of the winter layer may be seen at the bottom of the picture. Note the abrupt change from winter to summer conditions, as shown in the sizes of the grains. This clay is extremely fine. The long particles are laths of sericite. The magnification is 250 diameters.

In cut number 2 a lower magnification of 50 diameters was used. Here the abrupt change from winter to summer is seen. Near the top of the picture is a layer of finer material, denoting very quiet water conditions for a short period, and this again is followed by coarser material. In the entire summer component there are six or seven such changes. When this clay was deposited the water must have been relatively deep and very quiet, for the grains do not average more than 1/800 of a millimeter.

Cut number 3 is a section taken from the highest and thinnest seasonal layers at Woodsville. Here the water was shallower and the materials less abundant than in the layers lower down. The current action was more pronounced, as indicated by the sizes of the grains. At the top of the summer component and beginning of the fall and winter component some coarse grains

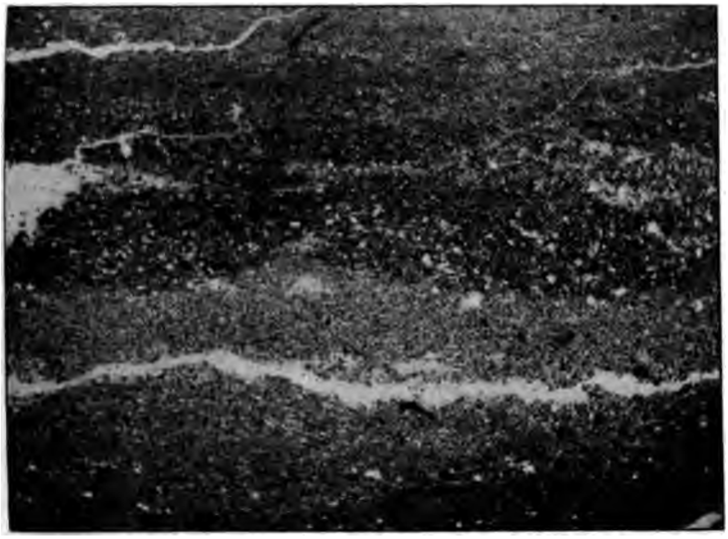

FIGURE 3.—*Section of Clay, Woodsville, New Hampshire*

may be seen. Above this zone, however, the grains are extremely fine throughout. The magnification in this case is 35 diameters. This coarse material at the end of summer and beginning of fall is also characteristic of similar layers in the Squantum slate, which is a glacial slate.

I have given wind action as a possible explanation of the coarse grains mingled irregularly, or in a definite layer, through the fine material of autumn or spring. The beginning of cyclonic control of the atmospheric circulation in early fall, with high winds, might very well blow coarse grains into the basin of deposition before the winter ice cover had formed to prevent the access of such grains to the deposit. In the spring the melting of the ice cover, with its included sand grains, would allow these grains to settle to the bottom. Some parts of the ice cover would have more dirt than other parts, and this would explain the less frequent occurrence of coarse material in the early spring horizon of deposition. In the autumn horizons the finding of the

coarse grains, although not invariable, is a very much more common phenomenon than in the spring.[1]

In cut number 4 there is shown a section of till from the drumlin called Winthrop Head, in Boston Harbor. The magnification in this case is about diameters. On the left is a pebble; then comes a crack separating this pebble from the matrix on the right. The finest material is a clay. A microscopic

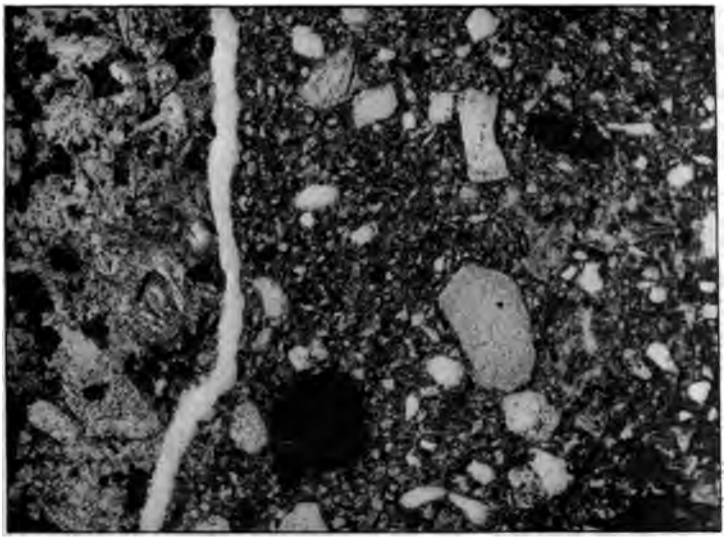

FIGURE 4.—*Section of Till from the Drumlin, called Winthrop Head, Boston Harbo*

examination of this till matrix gives the following minerals in the order their importance: sericite, quartz, orthoclase, microcline, microperthite, oligoclase, andesine, biotite (?), hornblende, and olivine. Some of the feldspar much altered, showing kaolin. The olivine also shows much alteration. The structure of the till needs no explanation.

With this method of hardening soft materials for grinding, it should be possible to examine annual deposits now forming, and thus to obtain some idea of the difference between our present seasons and the seasons of Pleistocene and earlier times.

METAMORPHISM IN METEORITES

BY GEORGE P. MERRILL

(*Abstract*)

The paper gives the results of studies tending to show that the crystall chondrites as well as stones of the white gray and intermediate groups or

[1] R. W. Sayles: Seasonal deposition in aqueoglacial sediments. Memoirs of the Museum of Comparative Zoölogy, vol. xlvii, no. 1, 1919, p. 49.

nate through metamorphism by heat and perhaps pressure of the tufaceous forms. The evidences of this are briefly summarized as follows:

I. By heat:

(1) The presence, in the forms mentioned, of the interstitial feldspathic glass, maskelynite, and calcium phosphate, merrillite.

(2) The absence of glass, other than maskelynite, in the chondrules.

(3) The presence in the interstices of fine granular polarizing particles and the "netzbroncit" structures of Berwerth.

II. By pressure:

(1) The granulation of the radiate enstatite chondrules and their gradual merging into the crystalline ground.

(2) The distortion, and at times almost obliteration or destruction. of a chondrite of whatever type.

The paper is regarded as but a preliminary announcement of results to be given in detail later.

Presented by title at the request of the author.

PORPHYRITIC GRANITIC GNEISSES, INTERPRETED AS LIT-PAR-LIT INJECTIONS OF SCHISTS

BY JAMES F. KEMP

(*Abstract*)

Observation of a so-called porphyritic, gneissoid granite in the Salmon River Canyon of Idaho the past summer convinced the writer that it was an injected biotite schist. The case was described, with comments on others of similar nature in the East.

Presented without manuscript.

ORIGIN OF ADIRONDACK MAGNETITE DEPOSITS [1]

BY WILLIAM J. MILLER

(*Abstract*)

In 1919 the writer published a paper on the "Magnetic iron ores of Clinton County, New York" (Economic Geology, volume 14, pages 509-535), special attention being given to the elaboration of a new theory of the origin of the ore deposits, particularly the large deposits now being mined at Lyon Mountain. Certain criticisms of that theory have been published by Newland (Economic Geology, volume 15, 1920, pages 177-180). It is the purpose of the present paper to reinforce that theory by additional evidence from field and laboratory, to apply the theory to Adirondack non-titaniferous magnetite deposits in general, and to answer Newland's criticisms.

The problem of the origin of magnetic iron ore deposits has been a puzzling

[1] Published by permission of the State Geologist of New York.

one, much discussed for many years. Any light which may be thrown on the problem by a study of the Adirondack magnetites is of special interest, because they comprise some of the most important deposits on the continent, especially those now being worked at Mineville and Lyon Mountain and in the abandoned mines at Hammondville. Most of the important mines have been visited by the writer.

According to the writer's theory, a gabbro or metagabbro older than the great syenite-granite series was the main or sole source of the magnetite deposits, and the derivation of the ore from the gabbro and its concentration into large deposits was accomplished by the intrusion of the syenite-granite magma, more especially its residual pegmatitic and silexitic portions, rich in hot gases, vapors, and fluids (mostly water).

The almost, if not quite, constant direct association of the non-titaniferous magnetic iron ores throughout the Adirondacks with granite, particularly where it is rich in pegmatite or silexite, and an older metagabbro (in many cases more or less thoroughly injected or assimilated) is a fact which can not be too strongly emphasized. One of Newland's main criticisms is that "admixture (of the granite) with foreign material seems to have no bearing on the distribution of the ores in general," except to some extent in the Lyon Mountain district. With this statement the writer flatly disagrees, and this disagreement is based on a great many observations made at magnetite localities throughout the Adirondack region during the last fourteen years.

Newland is very skeptical in regard to the derivation of the ore from the old gabbro and says that convincing quantitative evidence is lacking, and this in spite of the fact that detailed statements, backed up by chemical analyses, are presented in the writer's paper. Field studies, supported by study of many thin sections, shows that, in and around the ore deposits, tremendous quantities of iron-poor diallage have resulted from transformation of the iron-rich minerals of the old gabbro by the action of the granite magma and pegmatite. Obviously, then, large amounts of iron oxide were set free. But what became of so much iron oxide? According to the writer's theory, it was taken up in the pegmatitic solutions, carried along, usually not very far, and concentrated as ore deposits. How would Newland answer this question?

Newland thinks there is no difficulty in the way of explaining the ore deposits as magmatic segregations in the granite itself. If the ores are straight magmatic segregation deposit of the granite, why did not at least some deposits of considerable size develop well within portions of the granite free from admixture with old gabbro?

Presented by title in the absence of the author.

MAGNETITES OF NORTH CAROLINA—THEIR ORIGIN

BY WILLIAM SHIRLEY BAYLEY

(*Abstract*)

In his discussion of the magnetite ore at Cranberry, North Carolina, Mr. Keith ascribed its origin to solution emanating from the "Bakersville gabbro," which he believed to be of Juratrias age. In the summer of 1919 the magnet-

ites of western North Carolina [1] were examined and it was discovered that the Cranberry magnetite vein is much older than Juratrias time, since its gangue is crushed and is penetrated by veins of pegmatite which, so far as known, occur only in the pre-Cambrian rocks of the district. Consequently the ore deposit could not have owed its existence to the Bakerville gabbro, if this is Juratrias.

The gangue of the Cranberry ore is characterized by an abundance of epidote and hornblende. The epidote is clearly derived from the feldspar of a pegmatite and the hornblende from pyroxene.

The pegmatite appears to have been an augitic variety and the magnetite that forms the ore bodies is closely associated with it.

After describing several thin sections of the ore and gangue, the conclusion is reached that the ores are pre-Cambrian in age and that they were deposited by an intrusion of pegmatite which brought with it richly ferriferous solutions.

The titaniferous ores of the region, on the other hand, are believed to be genetically connected with peridotites, since serpentine or some similar mineral is nearly always associated with them.

Read from manuscript.

Professor Bayley's paper was discussed by Professors T. L. Watson and U. S. Grant, with reply by the author.

Discussion

Prof. T. L. Watson: Of the two principal types of magnetite deposits in western North Carolina, titaniferous and non-titaniferous, Professor Bayley regards the latter of pegmatitic origin, while the genesis of the former is in doubt, because of lack of sufficient data regarding them. At one locality only were the ore bodies found in association with limestone.

Similar lens-shaped bodies of magnetite of varying size and richness, including titaniferous and non-titaniferous varieties, occur in many localities in the Blue Ridge and Piedmont Plateau provinces of Virginia. So far as these have been investigated, most of them are apparently inclosed in crystalline schists, with which they usually conform in structure. Some of the magnetite bodies of the Piedmont province are intimately associated with quartzite and crystalline limestone, while at least a part of those of the Blue Ridge province are associated with rocks of undoubted igneous origin. The geology of the Virginia magnetite bodies, now under investigation by the Virginia Geological Survey, strongly suggests that a common genesis can not be ascribed to all of them, but that several different genetic types are represented.

Prof. W. S. Bayley: Three types of magnetic ores are to be found in Ashe County. So far as I know, the titaniferous ores are associated with peridotites and the non-titaniferous siliceous ones are associated with rocks like those at Cranberry. These I think are pegmatitic in origin. Of course, this report is preliminary only. So far as I have seen the non-titaniferous magnetites of Ashe County, they are identical in all respects with the ore at Cranberry.

[1] U. S. Geol. Survey, Folio No. 90, p. 8.

COBALT-NICKEL-COPPER-LEAD DEPOSITS OF FREDERICKTOWN, MISSOURI

BY W. A. TABB

(*Abstract*)

These interesting cobalt-nickel-copper-lead deposits have been worked more or less for lead for 200 years, but only within the last 20 years has an attempt been made to produce the first three metals. The cobalt and nickel occur as linnæite and the copper as chalcopyrite. These minerals are more or less intergrown and are associated with pyrite, spalerite, and galina. The ores occur at the top of the La Motte sandstone (Cambrian) and at the base of the Bonneterre dolomite (Cambrian). Some post-mineralization faulting has occurred. The bearing of the origin of these deposits on the origin of the lead deposits in Missouri is discussed.

Presented by title in the absence of the author.

GEOLOGIC HISTORY OF THE COROCORO COPPER DISTRICT, BOLIVIA

BY JOSEPH T. SINGEWALD, JR., AND EDWARD W. BERRY

(*Abstract*)

A more detailed study of the Corocoro copper district in Bolivia than has hitherto been attempted has developed the fact that, instead of the two series of strata previously recognized, the Corocoro sediments include three thick series of beds. In addition to the well known "vetas" and "ramos" is a third group, lithologically similar to the "ramos," but unconformably overlying both the "vetas" and the "ramos," which is called the Desaguadero series. Detailed measured sections of part of the "vetas" and of the "ramos" include over 3,000 feet of the former and 12,000 feet of the latter.

The "vetas" contain cupriferous horizons throughout the section, and many of these beds include an abundance of fossil plants of Pliocene age. Locally the "vetas" consist of large quantities of fragments of porphyritic rocks of the same character as the Tertiary igneous intrusions of the region, showing that the mineralization followed after the igneous activity. The age of the "ramos" can not be so definitely fixed, but they are also mineralized over a wide range of the section and are older than the period of mineralization. A macrauchenis skeleton found in the "ramos" makes them of either Pliocene or Pleistocene age. A footprint of an edentate is all that the Desaguadero series at Corocoro has yielded in the way of fossils. It indicates a late Pliocene or Pleistocene age for those beds. They are unmineralized and younger than the mineralization.

The geologic history of the district portrayed by the Corocoro rocks commences in the Pliocene with igneous activity, during which the deposition of a great thickness of terrestrial sediments was initiated. After the deposition of the "vetas" and "ramos," they were uplifted, tilted, and faulted. Mineralization followed these disturbances, after which sedimentation was resumed and the Desaguadero series was laid down. The district was then again the

seat of tectonic disturbances, which were followed by the present cycle of erosion.

Presented by the senior author without manuscript.

SOME CONCLUSIONS IN REGARD TO THE ORIGIN OF GYPSUM

BY FRANK A. WILDER

(*Abstract*)

While the salt-pan theory for the origin of gypsum has been generally accepted, its difficulties have been generally recognized and have often been pointed out. While admitting that this theory best explains some gypsum deposits, it seems probable that many important bodies of gypsum owe their origin to other causes and conditions.

Professor Stieglitz has demonstrated that gypsum deposits that are free from calcium carbonate can not be accounted for by the salt-pan theory. Gypsum deposits of relatively recent origin of the salt-pan type are less important than those having different origin. Present-day gypsum deposits are, for the most part, efflorescent deposits, periodic lake deposits, spring deposits, and deposits due to the alteration of carbonate to sulphate. There is reason to believe that many important gypsum deposits of earlier periods owe their origin to similar causes.

Presented without notes.

Discussion

Prof. J. Volney Lewis: Surface efflorescence is quite general over the outcrop of gypsiferous Jurassic strata in Wyoming and Utah. Commonly this takes the form of spongy crusts, but in places along the stream channels powdery and granular gypsite, quite comparable to the Alamorgorda sands in character, but very limited in quantity, has accumulated. Concentration by ground water is also responsible for gypsum veins in many places, and the question has arisen in my mind whether even some of the purer intercalated gypsum beds themselves may not have originated in the same way.

FLOODING OF OIL WELLS BY FRESH WATER

BY THOMAS C. BROWN

(*Abstract*)

It is well known that oil wells are frequently flooded by fresh water, coming either from the surface or from porous strata penetrated by the well. The older view was that the hydrostatic pressure of the water entering from above forced the oil back into the rocks, or perhaps forced it off to some other outlet. This theory will not explain the failure of many oil wells caused by the entrance of fresh water.

In many of these wells the oil when pumped out is mixed with salt water, and yet if fresh water enters in any considerable quantity the oil ceases to come and only water can be pumped out.

It is suggested that this is a surface tension phenomenon. The pores in the rock through which the oil moves are very small, yet large enough so that they are not completely sealed by the capillary action of salt water with its relatively low surface tension. When this salt water is replaced by or diluted with fresh water, the surface tension is increased and the pores in the rocks are effectively sealed. Oil can no longer pass through them, but water can pass as usual. The oil is still in the rock but it can not get out.

Presented by title in the absence of the author.

The sectional meeting adjourned about 5.30 o'clock.

ANNUAL DINNER

The annual dinner of the Society was held at 7 o'clock Wednesday evening, at the Chicago Beach Hotel, in conjunction with the Paleontological Society, the Mineralogical Society of America, the Society of Economic Geologists, and guests. About 175 persons were present and the affair was most enjoyable.

President White presided at the opening, and after introductory remarks proposed that a telegram expressing the sympathy of the Society be sent to its former President, Prof. A. P. Coleman, who was in the hospital recovering from a serious operation, and that a telegram of greetings and best wishes be sent to another former President, Prof. J. J. Stevenson, who is confined to his home by the infirmities of age.

On motion, the Secretary was unanimously instructed to forward the messages.[1]

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[1] The telegrams were as follows:

Prof. A. P. COLEMAN,
Toronto General Hospital, Toronto, Canada:

Geological Society of America, assembled at its annual dinner, sends you cordial greetings and best wishes for a speedy recovery to health. Happy New Year!

EDMUND OTIS HOVEY, *Secretary.*

Dr. J. J. STEVENSON,
215 West 101st Street, New York City:

Geological Society of America, assembled at its annual dinner, sends warmest greetings to you, its beloved former President, and best wishes for a Happy New Year.

EDMUND OTIS HOVEY, *Secretary.*

Professor Stevenson replied as follows:

215 WEST 101ST STREET, NEW YORK CITY, *January* 1, 1921.

Dr. E. O. HOVEY,
Secretary, Geological Society of America.

MY DEAR SIR: Your telegram reached me too late on Thursday for immediate reply, as it would not reach your hotel until after adjournment of the Society, so acknowledgment has been deferred until now.

A man would have to be more or less than human in order to be indifferent to a message such as that sent by you. Being only a mere man, I am deeply moved by it: the more so because during more than twelve years I have been shut off from the meetings and have become little more than only a name to almost a majority of the Fellows. Be assured that I am grateful for the remembrance.

Sincerely yours, J. J. STEVENSON.

Doctor White then surrendered the chair to Prof. James F. Kemp, who served as toastmaster for the remainder of the evening. The following men responded to his genial demand for remarks: Prof. T. C. Chamberlin, Dr. R. A. F. Penrose, Jr., Dr. Philip S. Smith, Prof. F. B. Loomis, Dr. George H. Ashley, Prof. F. R. Van Horn, Prof. H. L. Fairchild, and Prof. A. C. Lawson.

Session of Thursday Morning, December 30

The Society convened in the auditorium of Rosenwald Hall at 9.55 o'clock Thursday morning, President I. C. White in the chair. There being no business to transact, the presentation of the papers on the program was taken up at once.

TITLES AND ABSTRACTS OF PAPERS PRESENTED AT THE MORNING SESSION AND DISCUSSIONS THEREON

MOUNT WHEELER AND LEHMAN CAVE, WHITE PINE COUNTY, NEVADA

BY JOHN B. HASTINGS

(*Abstract*)

The trip from Ely, Nevada, up Steptoe Valley, across Shell Creek Range, Spring Valley, and Snake Range, to the cave in Snake Valley at foot of east flank of Mount Wheeler, describing the bird's-eye view en route of Mount Wheeler uplift, with photos.

Ascent of Mount Wheeler, glimpsing the stratigraphy on the east and north slopes, as spirally exposed from base to summit. An inclusion of schist in the older granite, with photos.

Map and photos of the cave interior. Description of its structure and analysis of the white and blue lime walls and aragonite deposit.

	Blue lime.	White lime.	Blue lime.	Stalagmite.
SiO_2	0.24	0.19	0.57	0.10
Al_2O_3	0.16	0.19	0.13	0.04
Fe_2O_3	0.24	0.24	0.63	0.01
CaO	53.74	55.28	53.96	55.00
MgO	1.54	0.26	0.91	0.18
SO_3	0.03	0.09	0.05	0.14
Water, 100° C.	0.06	0.02	0.26	0.36
CO_2	43.86	43.67	43.35	43.37
Ignition loss	0.22	0.03	0.13	0.89
Total	100.10	99.97	100.01	100.10

Presented by title in the absence of the author.

GEOLOGICAL NOTES ON PALESTINE

BY R. W. BROCK

(*Abstract*)

The rocks range from pre-Cambrian to recent, but the country is underlain largely by Cretaceous limestones and recent basalts.

The main structural features are faulting; the Judean hill country is an asymmetric fault-block. Fault-blocks usually sink without much tilting, but the Jebel Usdum block is upturned.

The topography is dependent on structure, even down to details. Some of the volcanoes at least have been extruded from faults. The Jordan trench was filled to a height of about 1,400 feet above the present level of the Dead Sea during a pluvial period, perhaps coincident with the glacial. There has been no marked warping since.

The prepluvial canyons of the rivers Arnon and Zerka Main indicate a climate slightly drier than the present and a rapid change to pluvial conditions.

The beds laid down by the disappearing Jordan Lake were formed within a period of less than 30,000 years.

The salts in the Dead Sea that have not yet reached the saturation point would be accumulated in less than 50,000 years.

Geological evidence points to a dry climate ever since the pluvial period. At present the climate is a little less arid than formerly.

Presented from notes and with the aid of lantern slides.

Discussion

Prof. A. C. Lawson: Modern earthquakes in the region of the valley of the Jordan show that the movements which gave rise to the graben are still going on. I should like to ask if the old lake beds of the valley show the effects of faulting, or whether the valley which traverses them is due to erosion as the waters of the lake fill.

The author replied to Doctor Lawson: The lake beds show very slight faults, but the striking feature is their undisturbed condition, notwithstanding that movements and heavy earthquakes are still taking such as that which destroyed Tiberias.

To a query regarding the occurrence of petroleum, the author said: There are a few oil seepages in the Nubian sandstone, on the east shore of the Dead Sea, from the lower beds of the Upper Cretaceous toward the southeast end of the Dead Sea. The floating asphalt indicates seepage from the fault in the bed of the south lagoon.

FINAL STAGES IN THE PHYSIOGRAPHIC EVOLUTION OF THE SAN JUAN MOUNTAINS [1]

BY WALLACE W. ATWOOD

(*Abstract*)

The field studies on the physiography of the San Juan Mountains have been reported on from time to time at the meetings of this Society. As the studies

[1] Presented with the permission of the Director of the U. S. Geological Survey.

have progressed, more and more details have been worked out, and during the past season the work at the eastern margin of the range led to certain conclusions as to the relationship of the physiographic history of the mountain range to that of the San Luis Valley. An excursion was made southward into New Mexico for correlation purposes, and a more extended excursion was made to the southwest over the Colorado Plateau to correlate the great physiographic surfaces within the mountain areas with those of that famous plateau.

Presented without notes, with the aid of diagrams.

TERTIARY HISTORY OF THE LOWER SNAKE RIVER VALLEY, SOUTHWESTERN IDAHO

BY JOHN P. BUWALDA

(*Abstract*)

Mammalian remains recently collected in southwestern Idaho indicate that the Payette formation is not Eocene (?), but Middle or Upper Miocene, that a younger formation of Pliocene age is also present, and that the Idaho formation is Pleistocene instead of Pliocene. The rhyolite flows are mainly, if not entirely, late Miocene or Lower Pliocene, and the eldest basalts are Middle or Upper Miocene and no doubt represent part of the Columbia River lava series. Pleistocene basalts also occur. The results tend to indicate that the Idaho erosion surface is Neocene, possibly Pliocene, in age, instead of Eocene.

Presented by title in the absence of the author.

PHYSIOGRAPHIC DIAGRAM OF THE UNITED STATES

BY ARMIN KOHL LOBECK

(*Abstract*)

Unlike the usual block diagram, this one avoids distortion due to perspective. A base map of the United States on a scale of 1:2,500,000 has been used. The original drawing is thus about 76 x 48 inches in size and is to be reduced about one-sixth for publication, giving a final scale of 1:3,000,000. The topographic features of the country are to a certain extent exaggerated and idealized with the purpose of suggesting the underground structure and its relation to the topography.

The map is intended for use in teaching regional physiography and geology of the United States and as a base for laboratory exercises with classes.

It has been prepared with the additional purpose in mind of using it as a base for the plotting of the statistics soon to appear in the new Census reports. Owing to the fact that it is not distorted and that it is based on a map of the country showing county boundaries, it will be possible to prepare an outline county map to assist in plotting data relating to population, agriculture, railroads, industries, forests, mining, and irrigation, as these data are given by counties in the Census reports. Thus the diagram can be used to work out geographic and physiographic control as it has been exerted on human affairs. Hence it will be of value not only to the physiographer and geologist, but to the geographer as well.

Presented without manuscript, with maps.

TRUE SPHERE OF PETROLOGY

BY CHARLES P. BERKEY

(*Abstract*)

Petrographers have been so occupied with the task of asserting and classifying and grouping together so many historically quite unlike things that those who naturally follow the leaders in their science have entirely missed its true field, both in its educational and its geological bearings. An attempt will be made to point out what this sphere is.

Read from manuscript.

VOLCANOLOGY OF THE HAWAIIAN ISLANDS

BY HENRY S. WASHINGTON

(*Abstract*)

A brief account was given of the general volcanology of the islands. The well known succession from northwest to southeast was pointed out, and the coincidence between this and the same succession in the progress of Pele, the goddess of the volcanoes, according to native legends, was mentioned. After a brief account of the petrology of the islands, the dominance of basaltic, and to a less extent of andesitic, lavas, with the sporadic occurrence of trachytic and other alkalic types, was described; the paucity of our knowledge of the lavas of most, or all, of the islands was dwelt on, and the need for further collection and study, both in the field and in the laboratory, was urged.

There would seem to be, so far as one may judge from the present insufficient data, a distinct variation in the chemical composition of the erupted magmas with time, the earlier flows being generally more salic and more alkalic, and the later ones more femic and more calcic. Many more analyses are needed to solve the problems presented. The suggestion was made that possibly beneath the great, recent flows of basalt, as at Mauna Loa and Kilauea, are cores of much more alkalic lavas, possibly trachytic or phonolitic, which represent the earliest phase of volcanicity, such as are seen at Ferru and Arci, in Sardinia, and at other volcanoes.

The fact that all the inclusions in the lavas throughout the islands are of igneous rocks (gabbros, pyroxenites, lherzolites, and dunites) and the complete absence of inclusions of continental rocks, such as gneisses, schists, quartzites, or limestones, was pointed out and the bearing of this on some problems of the insular botany and zoology, postulating the existence of a former continental mass or connecting bridges, was mentioned.

Presented without manuscript, with lantern-slide illustrations.

ORIGIN AND COMPOSITION OF CERTAIN OIL SHALES

BY REINHARDT THIESSEN [1]

(*Abstract*)

This paper comprises part of a preliminary report on the microscopical study of oil shales.

[1] Introduced by E. O. Hovey.

A shale is generally defined as a rock formed by the consolidation of clay, mud, or silt, having a fine laminated or fissile structure. When such a rock contains bituminous or organic matter enough to yield oil, gas, and tar on distillation, it is called oil shale.

The Chocolate shale of the Devonian of Illinois has formed the basis of this study. The New Albany Black shales of Indiana and the Ohio shales of Kentucky were also studied and closely compared. Shales of other geological formations and from other States and countries were also compared.

The oil-bearing shales from the Devonian of Illinois, Indiana, and Kentucky are quite similar and what is said of the one is true of the other with but few exceptions.

The shale is in the main composed of three distinct components: clay, pyrites, and organic matter. These three constituents vary in proportion from place to place and from layer to layer, sometimes in close succession. The clay may be said to form the base in which the other components are imbedded, and generally constitutes the largest proportion.

The main bulk of the clay consists of very fine grains, but intermixed with this is always a varying percentage of larger crystalline grains. The finely divided clay can not ordinarily be distinguished from the organic matter, even at higher magnification, while the larger grains are easily distinguished at a magnification of from 200 to 1,000 diameters.

The organic matter consists largely of spores or spore matter, some cuticular matter, and unidentifiable darker-colored organic matter. At a magnification of 200 diameters numerous rather large spores are clearly seen to be imbedded in a mass of light to dark grayish brown color, together with numerous opaque pyrite particles. Several types of these spores are distinguishable. Some of them are probably the spores called *Sporangites huronensis* by Dawson.

At a much higher magnification, at 1,000 diameters or over, the organic matter lying between the larger spores is resolved mainly into four kinds of constituents: (1) fragments of the larger spores in all stages of comminution; (2) very small thin-walled spores; (3) cuticular matter in all stages of comminution, and (4) darker-colored organic matter.

The smaller spores are very poorly preserved and are recognized with difficulty. The darker-colored organic matter is not identifiable, but probably constitutes the degradation matter of various plant tissues and substances. Little or no resinous matter is present.

Very small globules of pyrites are quite uniformly distributed through the shale. The particles are quite similar to those found in the coals, but are more uniformly distributed, much more numerous, and on the whole smaller in size than those in the coals.

Samples of oil shale from Scotland were found to be very similar to the Devonian shales of Illinois, Indiana, and Kentucky. Oil shales of the Pottsville of Kentucky are also similar to these, but contain a larger proportion of organic matter other than spores.

Presented with the aid of lantern slides.

Doctor Thiessen's paper was discussed by Dr. David White, but further discussion was postponed to the afternoon session and at 12.30 o'clock recess for luncheon was taken.

Session of Thursday Afternoon, December 30

The afternoon session began at 2.07 o'clock, with President I. C. White in the chair. The discussion of Doctor Thiessen's paper was continued.

Discussion of Doctor Thiessen's paper continued

Prof. Frank R. Van Horn: I would like to point out to Doctor Theissen that a probable reason for the Marcellus shale differing in structure from the Devonian shales of Illinois, Tennessee, and others of later age from Colorado and Utah is that the Marcellus, in my experience, is more highly calcareous. It is filled with brachiopod remains. Correspondingly, it is less dense and therefore more porous and allows later structures to form in three directions across the bedding and is not limited to two directions in more dense argillaceous shales.

The constant presence of pyrite in all these sections may throw considerable light on the formation of concretions and possibly on their origin. In a previous paper Dr. W. A. Tarr argues for the syngenetic origin of concretions. Some of the shales in this paper certainly show that these pyrite cubes and concentric concretions were formed later than the stratification planes. I wish also to suggest that these pyrite concretions may have been formed by the reduction of ferrous sulfate solutions by the large amount of vegetable matter in these oil and other shales. All are familiar with the ironstone concretions from Mazon Creek, Illinois, with the fossil forms at their centers. I once heard of a mouse falling into a jar of iron sulfate and being converted completely into pyrite. I think we have here an analogue caused by vegetable matter. I feel that many other pyrite or marcasite concretions may have been formed in a similar manner. As to the original source of the iron solutions, I have no suggestions unless they came from previously overlying strata.

TITLES AND ABSTRACTS OF PAPERS PRESENTED AT THE AFTERNOON SESSION AND DISCUSSIONS THEREON

DEMONSTRATION MATERIAL IN GEOLOGY

BY HERDMAN F. CLELAND

(Abstract)

This paper describes some demonstration material which the author has found useful in the teaching of geology in the lecture-room and laboratory. It is offered in the hope that some plan will be suggested by which all teaching geologists may be able quickly to learn of useful apparatus or models that have been devised and where and how especially desirable specimens of weathering structure, ores, etcetera, may be obtained.

Presented by title in the absence of the author.

CRYPTOVOLCANIC STRUCTURE IN OHIO OF THE TYPE OF THE STEINHEIM BASIN

BY WALTER H. BUCHER

(Abstract)

The Steinheim Basin is a circular structure less than 1¼ miles in diameter.

located in the nearly level strata of the Swabian plateau. In its center the beds have been raised nearly 500 feet above their normal level, while, surrounding this central uplift, a ring-shaped area has been depressed by a similar amount below the original level, being separated from the undisturbed strata of the plateau by strong faults. With the possible exceptions of the near-by Ries-basin, it has thus far been the only known representative of this type of structure, for which Branco and Fraas have proposed the term "cryptovolcanic."

A strictly analogous structure in Adams County, Ohio, measuring over four miles in diameter, was mapped by the writer in the summer of 1919.

It was discussed with the aid of the geological map and of diagrams and photographs.

Presented without manuscript.

Discussed by Professors T. C. Chamberlin, G. H. Chadwick, and W. A. Tarr.

PROBABLE CAUSE OF THE LOCALIZATION OF THE MAJOR GEOSYNCLINES

BY WALTER H. BUCHER

(Abstract)

The existing theories which attempt to explain the narrow belts of intense folding in contrast with the large unfolded elements of the earth's surface are inadequate, because they all fail to account simultaneously and satisfactorily for two most fundamental facts: the rising of the mountain folds out of preexisting geosynclines and the design formed by these labile belts on the earth's surface.

Haug's reconstruction of the geosynclines of post-Paleozoic time was discussed. Special emphasis was laid on the parallelism existing between these geosynclines and those of Paleozoic time, and its bearing on those parts of his reconstruction which at first glance seem purely hypothetical.

The result of a series of simple experiments made by the writer were presented, in which this design has been duplicated in all its essentials through the deformation of glass spheres in a manner which directly implies the possibility of the formation of geosynclines along the prescribed lines on a sphere of the earth's constitution.

An interpretation of these results in the light of the deformation characteristic of the geosynclinal belts was offered.

Presented without manuscript.

POSTGLACIAL FAULTING ABOUT MOUNT TOBY, MASSACHUSETTS [1]

BY F. B. LOOMIS

The subject of faults of postglacial age has received some notice in New York and New England, small faults in the Champlain clays and breaks in

[1] Manuscript received by the Secretary of the Society January 13, 1921.

the continuity of the glaciated surfaces from other places being reported, these have all been matters of a few inches. The escarpments about Mo Toby have been discussed before this Society[2] and their cause attribute plucking by the glaciated ice. It is almost a tradition that New England c not offer recent diastrophic movements.

Two years ago, needing a much more accurate map of the Mount Toby gr than any which have been made to date, I set my geology class to mapping region, both topographically and geologically, and the accompanying map, ure 1, is the result. One feature came out from the first. The shoreline of postglacial Lake Hadley was not where it was supposed to be. Shortly a the glacial ice had disappeared Mount Toby was surrounded on the sou west, north, and part of the east by this considerable sheet of water, and streams from the mountain brought into the lake quantities of gravel a sand which were deposited in a very pretty series of deltas at the mouth each valley. The largest of the deltas is that of the Long Meadow Brook in figure 1), around the southeast and south end of the mountain, a delta tending two miles or more along the base of the mountain and with a wi of a mile or more in places. Today it stands almost perfect, except for a sm notch, where, since the draining of the lake, the brook, after crossing the de top, has cut a small piece out of the margin. This notch is unusually sm because the brook, except in highest water, sinks into the gravel of the del disappearing until it reaches the margin of this big deposit. The level fie on the top of this delta stand at 340 feet above sealevel, conforming with level of the shoreline along the east side of the valley hereabouts.

Traveling from this delta along the west side of Toby, the next delta is t of Dug Brook (*b* in figure 1), a small stream which has built a delta of so fifteen acres on the top; but this level delta top stands but 260 feet above level. From here northerly—in fact, from *f* to *c* in figure 1—the shorelin perfectly developed as a sandy bench from 25 to 300 feet wide on top. T continues up to a marked escarpment (*x-y* in figure 1), the whole dista from the Long Meadow delta to the escarpment being about three miles. yond the escarpment the shore is traced by a series of small deltas and a perfect shore bench, but is along the 340-foot level again.

The escarpment which cuts the shoreline is a clean-cut fault, or rathe double fault, for the descent from the upper to the lower level is made in steps—the first of 50 feet, the second of 30 feet. This fault, when first enco tered cutting the shoreline, trends north 10 degrees west for a quarter mile out into the old lake bottom; then it makes an abrupt turn to nort degrees east and continues a mile and more, gradually getting lower finally disappearing. This fault cuts the course of two brooks, and each t bles over the escarpments in two waterfalls. At the edge of each fall margin of the escarpment is scarcely notched, showing that these bro though in spring they carry heavy burdens of sand, have not yet had tim wear down the edge to a material extent. This fault must, then, be of l age than the period of the postglacial Lake Hadley, which was emptied by postglacial uplift of New England, the amount of uplift for this region be

[2] B. K. Emerson: The cirques and rock-cut terraces of Mount Toby. Bull. Geol. Am., vol. 22, 1911, p. 681.

according to Fairchild,[3] some 300 feet—less to the south and more to the north. Such an uplift would be expected to cause some fracturing of the unequally affected land-mass. This fault is described in detail because it can be positively dated—that is, between the time of Lake Hadley and the present.

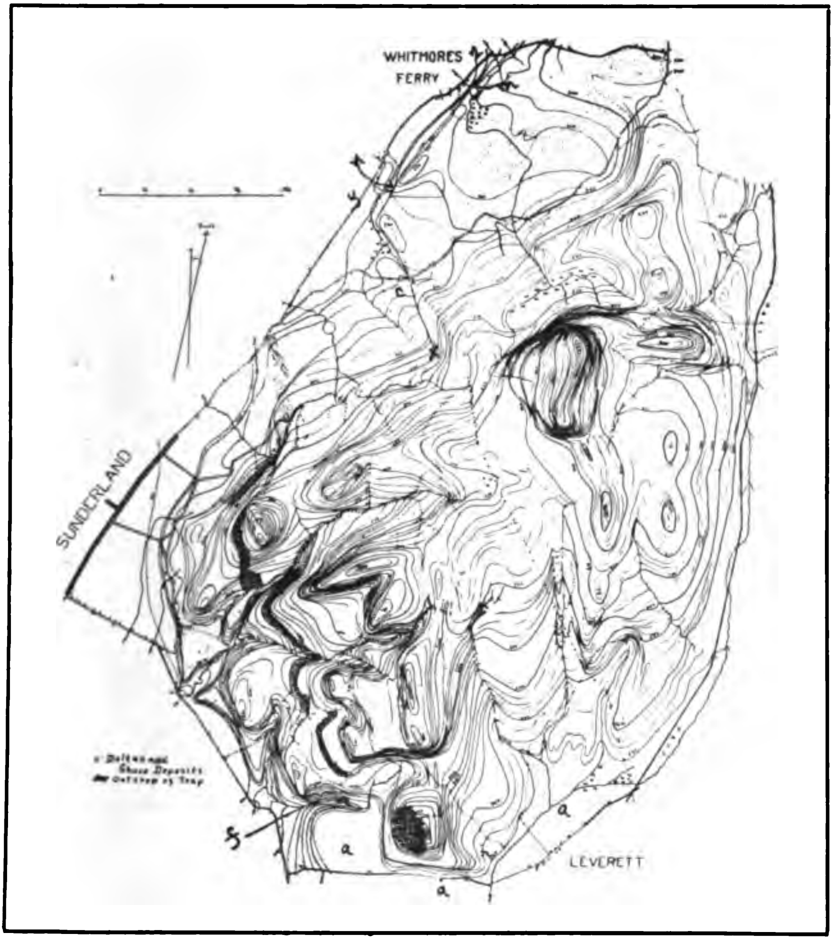

FIGURE 1.—*Map of Mount Toby, Massachusetts*

a, Long Meadow delta; *b*, Dug Brook delta; *c*, north end of down faulted area; *x-y*, fault shown in figure 2; *y-z*, fault shown in figure 3.

On Mount Toby there are dozens of fault escarpments breaking the glacier-smoothed rock surface, which about here is so little weathered. The Sunderland Cave is such a case. Here three parallel joints have formed, outlining

[3] H. L. Fairchild: Postglacial uplift of southern New England. Bull. Geol. Soc. Am., vol. 30, p. 597.

small blocks. Of these blocks the northernmost has dropped six feet; tl one, without dropping, has tipped to the north and rests against the first leaving a space two to six feet wide between the blocks. This is th On the south side of this last block a corresponding crevice gapes w opening some ten feet wide at the top and narrowing toward the rubbis

FIGURE 2.—*Escarpment of Fault, 50 feet of the Drop at n, shown on figure 1*

bottom far below. The tops of these blocks are glaciated, the walls ar and unweathered, and, though small, the fault is very young. On the west corner of the mountain, near the so-called "Bears Den," is anothe joints, the largest of which gapes and is filled with debris, a tiny brool nating in it. This trends northeasterly and is crossed by a north-t

fault on which the westerly block has dropped some 20 feet, and, tilting back against the fault face, makes a depression, now occupied by a frog pond. Back of the Tyler camp is an escarpment 60 feet high, with an entirely fresh and unweathered face, and one triangular block some 20 feet wide is caught and

FIGURE 3.—*Brook falling over Fault Escarpment, edge of which is not yet eroded*

left hanging half way down the fault face. I could enumerate twenty more such escarpments on Mount Toby of five to 50 feet high, with fresh and unweathered faces, and with glacier-smoothed top surfaces still extant. In general, one set of faults trends north, varying some ten degrees either way, and

the second set has a northeast trend; but these vary more than the first set. The small streams cascade over these escarpments and have not cut into the margins materially.

If the contour of stream profiles means anything, there are still other steep slopes which seem to be faults of slightly older appearance, but still postglacial. The whole mountain group—north, east, south, and west—has streams with broken profiles, and cliffs occur on every side, though more abundantly on the west. There are one or two hanging valleys which have been attributed to glaciers forming in the group; but there do not seem to me to be any indications of ice-fields (cirques) or glacial valleys. Faulting explains all the hanging valleys much more simply, especially when it is established that postglacial faulting occurred here on the scale of the fault that has just been described as cutting the shoreline.

In the Holyoke range and out among the Pelham Hills there are several sharp and clean-cut escarpments which have every appearance of being postglacial in age, since the glaciated surface is broken. While to date I have not found others which cut a postglacial shoreline, I am convinced that there has been considerable faulting in and about the Connecticut Valley some time since glacial times.

Discussion

Prof. W. H. Hobbs: I think I can add evidence of similar sort from the region of the Frivel River, Western Ontario. In a fortnight's canoe trip made in 1919 within that region it was discovered that whereas the district is one of almost no cover of unconsolidated materials and the hard pre-Cambrian rocks are shaped, scored, and polished in the most striking fashion, yet for long distances, sometimes a mile or more, escarpments run parallel to the river courses, and on these escarpments no trace of glacial action is to be found. Some of these escarpments were, by estimate, 100 feet or more in height.

If I seem to be offering this proof of my thesis offered before in these sessions, that the Atlantic region is in repose, by contrast with the Pacific, it is really so only in appearance. The mobility of the earth's crust in the Pacific area is yet vastly more mobile and the Atlantic region by contrast properly described as nearly at rest.

SIGNIFICANCE OF THE RELATION OF PROBOSCIDEAN REMAINS TO THE SURFACE OF NEBRASKAN GUMBOTIL, NEAR OSCEOLA, CLARKE COUNTY, IOWA [1]

BY GEORGE F. KAY

(Read before the Society December 30, 1920)

CONTENTS

[1] Manuscript received by the Secretary of the Society January 10, 1921.

Introduction

Two tusks and some limb bones of a mammoth or mastodon were found recently in the base of Kansan till which overlies Nebraskan gumbotil, about four miles southeast of Osceola, Clarke County, Iowa. It is the purpose of this paper to describe briefly the chief features of these remains and to indicate the probable significance of their relationships.

History of the Discovery

In August, 1920, Messrs. Earl Cox and Sharon Warrick uncovered a tusk when they were grading a north-south wagon road in the southern part of the northwest quarter of section 3, Greenbay township. Later, at the same place, Mr. Cox and Mr. Fred Stubbs began to excavate with the hope of finding the other parts of the animal from which the tusk had come. They soon dug up a second tusk and some limb bones. Unfortunately, on exposure, the tusks and bones quickly disintegrated, so that when the place of discovery was visited, in the month of October, it was possible to see only the fragments of the remains and some of the molds of the bones in the clay from which the fossils had been taken. Thanks are due Mr. Fred Stubbs for furnishing information about the bones and for pointing out the positions which they had before they were removed. Professors A. C. Trowbridge, A. O. Thomas, and R. W. Chaney, of the Department of Geology of the State University of Iowa, also visited the place of discovery. Each of these persons has offered helpful suggestions in the preparation of this paper.

The Fossils and their Relationships

In all, two tusks, a scapula, a limb bone which was probably a humerus, fragments of ribs, and some unidentifiable small pieces of bone were found. Absence of teeth precludes with any degree of certainty the generic determination of the proboscidean.

The fossils were imbedded in glacial till on the south slope of a hill about 100 yards from its base. A section taken along the wagon road from the base of the gently sloping hill to its summit shows the following kinds of glacial deposits:

	Feet
4. Glacial till (Kansan), oxidized, unleached along slope, inclusions of Nebraskan gumbotil near base, about	60
3. Gumbotil (Nebraskan), drab to dark colored, starchlike fracture, few siliceous pebbles, leached	4
2. Glacial till (Nebraskan), oxidized, leached, about	1
1. Glacial till (Nebraskan), oxidized, unleached, not well exposed, about.	40

The summit of the hill is less than 20 feet lower than the Kansan gumbotil plain, remnants of which are characteristic of this region.

The bones were within the lower 10 feet of the Kansan till and only about 50 feet up the slope from the outcropping surface of the Nebraskan gumbotil. The Kansan till is here oxidized, unleached, somewhat sandy, contains few pebbles, and has some inclusions of the Nebraskan gumbotil. The bones all

lay within 10 feet of the surface of the slope below which the road has been cut, and yet the evidence is clear that the bones became included in the till during the Kansan Glacial epoch and not since the development of the slope by erosional agencies.

The tusk which was found when the road was being graded was measured by Mr. Cox, who reports that it was 9 feet 7 inches long. The bones which were discovered later by excavation were about 10 feet distant from the first tusk. These bones were closely related one to the other; a shoulder-blade lay flat and end to end with a bone which from the description of Mr. Stubbs was probably a humerus; a tusk overlay the shoulder blade, and the other fragments were closely associated with these bones and in the same plane. The tusk which was lying on the shoulder-blade was measured by Mr. Stubbs, who found it to be 11 feet 4 inches long. This length was verified by a measurement of the mold of the tusk which was still distinct in the drift at the time of our examination. The mold in which the tusk lay showed no evidence of fracture, flattening, or other distortion. This tusk was curved in two planes; apparently when in position in its socket it curved downward and outward, then upward to the tip.

The tusks when exposed to the air crumbled into a white powdery substance. Pieces of only a few inches in diameter were seen intact, and these showed the concentric structure of ivory. The bones were so fragile that they crumbled at the touch; no pieces showed any sort of hardening. All the bones maintained their shape and were of a grayish white color. Although impregnated with soil the cancellated structure was distinct. A spade or pick passed through the bone as readily as if it were soft clay.

Significance of the Relationships of the Fossils

The tusks and limb bones were found in the base of Kansan till which overlies Nebraskan gumbotil. The characteristics of the tusks and bones and their relationships indicate fairly conclusively that they were parts of a single animal, the remains of which were lying on the surface of the Nebraskan gumbotil when they were picked up by the advancing Kansan ice, and that while they were being transported a short distance they became imbedded in the base of the Kansan till. The relation of the remains to the surface of the Nebraskan gumbotil, which is perhaps the most distinctive Aftonian interglacial horizon-marker which has yet been found, suggests strongly that the mammoth or mastodon had been living near the front of the Kansan ice-sheet during the Kansan Glacial epoch. If this interpretation is correct, then the habitat and the age of the mammoth or mastodon are here indicated more definitely than in many other places in Iowa where similar remains have been found in gravels. These gravels have been interpreted to be Aftonian interglacial gravels, related neither to the melting of the Nebraskan ice-sheet nor to the advance of the Kansan ice-sheet. In this connection it is of interest to state that recent study by the writer of many of the gravels in which proboscidean and other remains have been found suggests that at least some of the gravels are not distinctive interglacial deposits separating the two oldest drifts, the Nebraskan drift and the Kansan drift, but are lenses and irregularly shaped masses of gravels incorporated in till and related closely in age

to the till with which they are associated. If these gravels were deposited in front of an advancing ice-sheet and on a surface on which mammals were living, the gravels and their included fossil remains might later be plowed up by the ice-sheet and become incorporated in the drift with which the gravels are now associated. The evidence of the age and the habitat of proboscideans gained from the discovery near Osceola would seem to strengthen rather than weaken this interpretation. Moreover, it may be inferred, perhaps, that remains of mammals and other animals will be detected more rarely in till than in gravels, since the crumbly fossil bones which are imbedded in till are destroyed readily when a cutting is being made by a steam shovel or other machinery, whereas when the bones are in gravels they are likely to be silicified and therefore less likely to be destroyed, and hence more frequently detected.

Discussion

Dr. James H. Lees: I have recently examined a proboscidean tusk found at Des Moines buried in loess of Peorian age which lies on wind-blown sand overlying Kansan till. The animal evidently was living on the Kansan plain while the loess was being deposited—that is, later than the recession of the Iowan glacier. This occurrence, with that described by Doctor Kay as well as others, over Iowa and elsewhere, shows the range of proboscideans through a great part of Pleistocene time.

VOTE OF THANKS

A hearty vote of thanks to the Department of Geology of the University of Chicago, the local committee, and in particular to Prof. R. T. Chamberlin, was passed, in recognition of hospitalities extended and facilities supplied, making the Chicago meeting one of the most successful in the history of the Society.

PRELIMINARY SKETCH OF THE HISTORY OF THE LOWER MISSOURI [1]

BY FRANK C. GREENE

(*Read before the Society December 30, 1920*)

CONTENTS

Introduction

The following brief notes must be considered as far from complete, but it is believed that they are of sufficient interest to justify their presentation. They are the result of five years' observations made in connection with other work

[1] Manuscript received by the Secretary of the Society November 9, 1920.

done under the direction of H. A. Buehler, of the Missouri Bureau of Geology and Mines.

In parts of the Missouri Valley the Pennsylvanian rocks, in which the writer was principally interested, were found to be deeply buried by glacial drift, while in others only thin remnants of drift were found above the rocks forming the valley sides, usually high above the level of the floodplain. This condition prevails from Forest City to Kansas City.

Preglacial Platte Valley

The master preglacial stream of northern Missouri seems to have been a stream that entered the State at the northwest corner, flowed southeast, and joined what is now the Missouri at or near the mouth of Grand River. It united at this point with what was a continuation of Kansas River, and the stream thus formed followed approximately the course of the Missouri to its mouth.

That the northern stream was the continuation of the Platte (of Nebraska) seems highly probable. The first writer, so far as known, to suggest a buried valley under the Missouri was Captain Theo. A. Bingham. In his report[2] on the results of borings in the Missouri Valley he calls attention to the discovery, near Nebraska City, Nebraska, of a buried valley in which bedrock is 60 to 75 feet lower than it is a short distance to the north or south, or 165 to 175 feet below the level of the floodplain. This valley lies at right angles to that of the Missouri (about south 80 degrees east) and is filled with "very hard, tenaceous, drab-colored clay mixed with angular fragments of stone, generally of lime, though in one observed instance (boring number 23) of red quartzite, the prevailing boulder material of the northern glaciers." The suggestion is made that the Platte left its present valley at the abrupt turn about 20 miles above its mouth (at Southbend) and plowed southeast. The writer has not had the opportunity of testing this theory in the field, and therefore can offer no conclusive proof as to its correctness.

J. E. Todd[3] has suggested that the Platte may have crossed northern Missouri, following the present course of Grand River most of the distance. In this supposition he was only partially correct. Assuming the Platte crossed the present Missouri Valley at the place described by Bingham, it entered Missouri in Atchison County. The widening of Nodaway River between Quitman and Burlington Junction is due to the more rapid lateral erosion in the soft material of the buried valley. Maryville is situated over it, as shown by a boring there which passed through 170 feet of drift, although drilled down on the floodplain of One Hundred and Two River. The Wabash Railroad marks the location of the old valley as far east as Darlington. Grand River here bends to the south and occupies a rock-walled postglacial valley, whereas the buried valley continues to the east, crossing the southern part of Harrison County and the northern part of Grundy. Entering Linn County, it turns south and again coincides with Grand River from Fountain Grove to its mouth.

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[2] Report on borings in the Missouri River Valley. Missouri River Commission report, year ending June 30, 1890, published as Appendix XX to the report of the Chief of Engineers, U. S. Army, pt. 4, 1890, pp. 3375-3390.

[3] Science, new series, vol. xxxix, no. 999, February 20, 1914, pp. 263-274.

In Atchison County the ancient Platte received a tributary that crossed the Missouri between Napier and Craig, where erosion of the soft drift has helped to produce a very wide floodplain on the Missouri. The drift in this tributary is about 180 feet thick near Tarkio, as shown by the artesian wells along Tarkio Creek. On the western side of Grundy County and also in the eastern part of this county large tributaries were received from the north. The easternmost headed in Putnam County near the ancient Platte-Mississippi divide, in the Mendota coal field. Some of the branches cut down through the coal bed and the drift-filled gorges encountered in certain of the coal mines are the so-called "clay faults" of the miners.

The width of the ancient Platte Valley as determined by detailed mapping in Grundy County is six miles or more. The minimum occurs where it crossed the now largely buried escarpment of the Bethany Falls and other limestones at the base of the Kansas City formation. In comparison, the width of the present Missouri Valley where it crosses this escarpment is about five miles.

In Livingston County another large tributary seems to have occupied the valley of Shoal Creek and that part of Grand River Valley to the east. Other small tributaries may have been received from the east in Linn and Chariton counties. Throughout this system thick beds of sand and gravel overlain by boulder clay are common.

The gradient of the old Platte was about one foot per mile between Nebraska City and the mouth of the Grand. The lowest elevation of the surface of bedrock known at different points along the course is shown in the following table:

Altitude of Bedrock in the Valleys of the Ancient Platte and its larger Tributaries

Location	Altitude Feet
Nebraska City	758
Tarkio (on tributary)	726
Clyde	660±
Saline (on tributary)	610
Near Galt, less than	600
Triplett	554

The gradient of the present Missouri between Nebraska City and the mouth of the Grand is about 0.8 feet per mile.

Preglacial Kansas Valley

The preglacial Kansas Valley followed closely the present Missouri Valley between Kansas City and the mouth of the Grand. Its largest northern tributary in Missouri entered the State near Saint Joseph, flowed southeast via Trimble and through the valley now partly reexcavated by Fishing River. Where Smiths Fork of Platte River (not to be confused with the "Platte" of the previous pages) crosses the Saint Joseph Valley its floodplain becomes a mile wide, though less than half that width to the north and south.

A tributary of the Saint Joseph Valley in Platte and Clay counties possesses some peculiar features. Its bed is covered with a stratum of rounded limestone boulders overlain by gravel, sand, and drift, the latter resting uncon-

formably on the sand. At Weston this boulder bed appears high up on the Missouri River bluff at an altitude of 900 feet, near Tracy (Platte City station) at 846 feet; near Hoover, 835 feet, and east of Smithville, at the mouth of Crow Creek, at 800 feet—an average gradient of 10 feet per mile. The boulders in this valley are mainly of local limestone, but some northern material is present. Todd,[4] noting the boulder bed at Weston, attributed it to rapids of the Missouri at this point, but its relations show clearly that it is the deposit of another stream that crossed, at right angles, the site of the Missouri before the latter stream was formed. The stream that deposited the boulders and superjacent bed evidently had access to glacial debris, but formed the deposit before the region was glaciated.

Glacial and postglacial Changes

Of the changes in the ancient Platte River during glaciation the Missouri work has so far revealed nothing, probably because the course of the "Platte" was pushed far to the west in Kansas, as suggested by Todd.[5] The history of that part of the present Missouri east of Kansas City during this interval is clearer. With the Kansas River this part of the Missouri formed approximately the southern limit of glaciation, though the ice pushed south of the present valley in several places. In Jackson County are two abandoned valleys that seem to have been temporary outlets, and it is a significant fact that, so far as known to the writer, wherever glacial till occurs south of the Missouri River it lies north of one of these abandoned valleys. Another abandoned outlet appears to have been near Grand Pass, Saline County, and there are possibly others to the east, as there are known to be to the west, in Kansas.

The factors that determined the present course of the Missouri between Omaha and Kansas City are obscure and the writer has no suggestion to offer at this time. That the river has occupied its valley for some time is evident from the depth to which its rock floor has been eroded. From the data on borings previously mentioned, it is known that erosion has cut down to approximately 100 feet below the existing floodplain, and the valley then filled with that amount of clay, sand, and gravel. The bulk of this valley-filling material may have been derived from the rapid melting of some late ice-sheet in the northern States and the subsequent overloading of the Missouri.

POST-ILLINOISAN DRIFT IN NORTHERN ILLINOIS WEST OF THE MAPPED WISCONSIN MORAINE

BY MORRIS M. LEIGHTON [1]

(*Abstract*)

As a part of the new program of the Illinois Geological Survey in the reexamination of the Pleistocene of Illinois, recent studies have been made by the author in northern Illinois where the drift has an uncertain status. Sev-

[4] J. E. Todd: Formation of the Quaternary deposits. Missouri Geological Survey, vol. 10, 1896, p. 205.

[5] J. E. Todd: The Pleistocene history of the Missouri River. Science, new series, vol. 39, 1914, pp. 263-274.

[1] Introduced by F. W. De Wolff.

eral important lines of evidence—some of them new—will be presented which show that there are two distinct drifts west of the mapped Wisconsin moraine, the outer one being clearly Illinoisan in age, the inner probably early Wisconsin. While the precise boundary is yet to be drawn, yet it is quite plain that the Illinoisan drift extends in some places east of Rock River, and hence the new boundary must be radically different from the former Illinoisan-Iowan boundary.

Read from manuscript.
Discussed by Prof. R. D. Salisbury.

ORIGIN AND HISTORY OF LAKE CHELAN

BY J. J. RUNNER[1]

(*Abstract*)

The Chelan Basin, in north-central Washington, exhibits many striking effects of the work of glacial ice. Its linear form, abrupt, smooth slopes, and great depth have for some time been attributed to the erosive action of a large valley glacier. At its maximum development, the Chelan Glacier and its tributaries had a surface area probably exceeding 400 square miles. Its length was nearly 80 miles and its thickness throughout a considerable portion of its length doubtless exceeded 4,000 feet. For nearly 15 miles in its mid-section the bottom of the lake lies near to or below sealevel and its depth exceeds 1,000 feet. Data are now at hand to show that in this section several tributary hanging valleys that doubtless once entered the main valley at accordant levels now enter at elevations over 2,000 feet above the bottom of the latter. Locally, then, the amount of glacial erosion exceeded 2,000 feet, for these tributary valleys were glaciated and their floors lowered by a considerable but unknown amount. The deepest section of the lake occurs in the stretch where the valley is narrowest, which in turn coincides with the portion in which the structure of the rock is most favorable for down-cutting. Above the narrow, deep section the bedrock is dominantly granite and gneiss; below it is largely a complex of various fine-grained, igneous intrusives, while within this section the valley runs parallel to the strike of a steeply dipping series of schists and slates. Along the valley walls at the eastern end of the lake occur minor terraces marking the levels of small lakes that lay between valley spurs at the sides and the glacier in front.

Following the Chelan glaciation, after an unknown interval, came an invasion of the Cordilleran ice-sheet into the lower valley from the east. This blocked the natural drainage channel eastward to the Columbia River and caused the lake to rise first to an elevation of 1,800 feet and flow out through Navarre Coulee southward. Then, as the ice-tongue receded, the lake found a lower outlet through Knapp Coulee, at an elevation of 1,430 feet, and finally through the lower Chelan Valley, over the drift-dam, at 1,120 feet above tide. Since that time the level of the lake has been lowered by erosion of the outlet to 1,080 feet. The preglacial channel of Chelan River may be clearly seen one

[1] Introduced by George F. Kay.

mile above the station of Chelan Falls. The elevation of bedrock at this point and of striated bedrock in the Columbia River Valley, near by, is approximately 700 feet. Nearly 400 feet of the water of Lake Chelan, then, is held in by a drift-dam and the remainder lies in a rock basin.

Presented by title in the absence of the author.

ANCIENT ROCK DEFORMATIONS AND THEIR PRESENT EXPRESSIONS IN WESTERN VERMONT[1]

BY CLARENCE E. GORDON

(Abstract)

In western Vermont and contiguous areas the geology is greatly complicated by ancient deformations of the rocks due to compression. The formations involved belong to: (1) Pre-Cambrian; (2) Cambrian, chiefly Lower Cambrian; and (3) Lower and Middle Ordovician.

The stress has found expression in various kinds of internal deformation due to shearing strain, and in mass dislocation. It is not easy to apportion these different effects among the several disturbances which the rocks of the region have probably experienced, but the outstanding features due to compression may with much probability be attributed to one great, dramatic series of episodes in their history.

Internal deformation shows in various ways, and mass dislocations occur as folds and ruptures, which take the forms of small and large reverse faults and thrusts.

In the region of Lake Champlain, for many miles north and south, among the islands and along the shores of the lake, various eroded and now more or less detached masses of massive siliceous, magnesian, and calcareous rocks which have been metamorphosed in varying degrees, but which as a rule have not been violently folded, rest by thrust on other calcareous rocks and shales and slates which are younger and which have been folded and tilted, while at other places a quartzite, or quartzite-phyllite, formation rests by thrust apparently on the same slate formation.

There is evidence to show that some of the various calcareous rocks just mentioned as overlapping younger formations by thrust to the east of the lake now rest on the quartzite-phyllite formation, which is probably of Lower Cambrian age.

A reasonable interpretation seems to be that a great thrust cut through the Lower Cambrian basement of certain calcareous rocks belonging to different horizons of the Lower Ordovician and into the limestones along an irregular plane that emerged somewhere east of what is now the lake and drove the mass above the plane westward to its present resting place on the Trenton-"Utica" formation. As now eroded at some places, the contact of the Cambrian on the slates may be seen, while at others so-called "Potsdam," or Beekmantown, or possibly Chazy or Trenton, rests on the slates. No estimate seems possible of the eastward extent of the hidden overlap contact, but considerable lateral displacement appears probable.

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[1] Printed with the consent of the Vermont State Geologist.

The character and relations of the present erosion margin of the thrust depend on the character of the rock through which its plane passes along the particular meridian being examined. Furthermore, in many cases, what has been called "Logan's line" is apparently the result of normal faulting which has broken the thrusted mass and that beneath it. The margin or trace of the thrust, as now preserved, is marked by erosion remnants several miles away in the direction of the thrust, apparently even on the New York side of the lake.

In the Vermont Valley from Bennington to Brandon and along the eastern border of the Champlain lowland, as traced by the writer, there is at some places convincing evidence and at others strong indication of overlap of Lower Cambrian rocks (dolomites and interbedded dolomites and quartzites) on marble and other rocks of probable Ordovician age. It also appears extremely probable that Lower Cambrian terrigenous rocks consisting of schists and phyllites, with interbedded massive quartzites, have been thrust on marble and other rocks, and that in some cases such thrusted masses have been regarded as belonging to a younger terrane.

METHOD OF MEASURING AND PLOTTING THE SHAPES OF PEBBLES

BY CHESTER K. WENTWORTH [1]

(Abstract)

This method has for its object the measurement and portrayal on a chart of the features of the shapes of pebbles characteristic of their mode of origin. It consists in the measurement of the radii of curvature of the sharpest developed edge and the flattest developed face and plotting a simple function of these values on a chart. Pebbles are thus located on the chart according to their shapes, and river pebbles, glacial pebbles, dreikauter, and other sorts of pebbles have each their characteristic positions. This method permits quantitative study of the stage of rounding of river pebbles as well as the separation of pebbles of different origins and transitional types and promises to be of great aid in comparative interpretation of measurements of the shapes of pebbles.

Presented without notes, with lantern-slide illustration.

FIELD STUDY OF THE SHAPES OF RIVER PEBBLES

BY CHESTER K. WENTWORTH [1]

(Abstract)

Measurements of size and roundness were made on upward of six hundred river pebbles in the bed of Russell Fork of Big Sandy River, in southwest Virginia. The pebbles were all of quartzite from an outcrop near the head of the stream and were found at numerous places in the stream for over 28 miles. The increasing roundness is plotted as a function of distance traveled and,

[1] Introduced by A. C. Trowbridge.

taken in conjunction with laboratory determinations of the resistance to abrasion of these and other pebbles and measurements of the shapes of those pebbles, permits an estimate to be made of the distance traveled by the latter. Similarly, estimates have been made with reference to the persistence of glacial striæ during subsequent stream transportation of the pebbles, and other applications of this study have been made. In these estimates many assumptions are made concerning unknown factors which await evaluation from future studies of this sort, but the results, even with these limitations, are significant.

Presented without notes, with lantern-slide illustration.
Discussed by Dr. J. A. Udden.

REGIONAL STRUCTURE IN NORTH-CENTRAL TEXAS

BY E. H. SELLARDS

(*Abstract*)

The paper relates to regional structure in north-central Texas as determined from well records. The underground position of the pre-Cambrian formations is determined over a limited area adjacent to the Llano uplift in central Texas and in three counties adjacent to the Red River in northern Texas. The underground position of the Cambro-Ordovician formations is determined over a considerable area in north-central Texas. The regional structure is illustrated by one north-south and three east-west sections.

Presented in abstract without notes.

PALEOGEOGRAPHY AND CORRELATION OF THE MARINE TERTIARY DEPOSITS OF THE WEST COAST

BY BRUCE L. CLARK

(*Abstract*)

The purpose of this paper is to give a summary of the data up to date pertaining to the paleogeography and correlation of the marine west coast Tertiary deposits. Eleven paleogeographic maps will be presented with the paper, together with a tentative correlation table.

The aggregate thickness of the west coast Tertiary deposits exceeds 40,000 feet. The sediments, which for the most part consist of clastic materials, were laid down in geosynclinal troughs, a condition very similar to that which existed along the east coast of North America during the Paleozoic. Crustal movements were going on more or less interruptedly throughout the entire Tertiary period. The sea invaded and retreated many times from these inland basins. The contact between the deposits of these different cycles of deposition are usually well marked—in fact, in a large percentage of cases they are indicated by angular unconformities.

Presented in abstract without notes, with lantern-slide illustration.

PROBABILITY OF PENNSYLVANIAN GLACIATION OF THE ARBUCKLE AND WICHITA MOUNTAIN REGIONS

BY SAMUEL WEIDMAN

(*Abstract*)

The paper will describe briefly the evidence of the glacial origin of the Franks conglomerate of the Arbuckle Mountains and also will refer to a similar type of conglomerate of the Wichita Mountains. The Franks conglomerate occurs at the base of the Pennsylvanian and there are associated conglomerates of similar type at several higher horizons developing a series of thick conglomerates within the Pennsylvanian. The glacial origin of the conglomerate is indicated by: (1) The character of the conglomerates, such as the large size and variety of boulders; (2) the non-residuary character of the constituents of the conglomerate; (3) the great thickness of the conglomerate, up to 500 feet; (4) the presence of polished, striated, and faceted boulders and pebbles in the conglomerate; (5) the occurrence of polished, striated, and grooved surfaces on which the conglomerate rests.

Presented by title in the absence of the author.

DEVONIAN BLACK SHALES OF WESTERN NEW YORK

BY GEORGE H. CHADWICK

(*Abstract*)

Much greater thickness and extent of these possibly important oil-shales than previously reported have been shown by detailed mapping, especially in the case of the Dunkirk shale, which in eastern Erie County exceeds 160 feet of solid black.

Presented by title in the absence of the author.

The Society finally adjourned about 5 o'clock and the Thirty-second Annual Meeting came to an end.

Register of the Chicago Meeting

FELLOWS

G. B. Ashley
W. W. Atwood
R. M. Bagg
R. S. Bassler
E. S. Bastin
A. M. Bateman
W. S. Bayley
C. P. Berkey
J. A. Bownocker
E. B. Branson
J. H. Bretz
R. W. Brock
H. A. Buehler
B. S. Butler
E. M. Burwash
J. E. Carman
E. C. Case
G. H. Chadwick
R. T. Chamberlin
T. C. Chamberlin
B. L. Clark
G. L. Collie
A. R. Crook
G. E. Culver
E. R. Cumings
E. De Golyer
F. W. De Wolf
R. E. Dodge
W. H. Emmons
H. L. Fairchild
O. G. Farrington
N. M. Fenneman
A. F. Foerste
J. H. Gardner
L. C. Glen
M. I. Goldman
C. H. Gordon
U. S. Grant
H. E. Gregory
W. F. E. Gurley
C. A. Hartnagel
A. O. Hayes
D. F. Hewett
W. H. Hobbs
T. C. Hopkins
E. O. Hovey
W. F. Hunt
A. Johannsen
R. H. Johnson
W. A. Johnston
G. F. Kay
J. F. Kemp
E. M. Kindle
E. H. Kraus
G. F. Kunz
A. C. Lawson
J. H. Lees
C. K. Leith
A. G. Leonard
J. V. Lewis
W. Lindgren
W. N. Logan
F. B. Loomis
G. D. Louderback
P. McKellar
E. B. Mathews
K. F. Mather
W. J. Mead
G. P. Merrill
A. M. Miller
W. G. Miller
H. D. Miser
D. W. Ohern
W. A. Parks
F. B. Peck
R. A. F. Penrose, Jr.

W. C. Phalen
H. Ries
E. S. Riggs
W. N. Rice
R. D. Salisbury
E. H. Sellards
C. W. Shannon
E. W. Shaw
B. Shimek
J. T. Singewald, Jr.
P. S. Smith
R. E. Somers
J. E. Spurr
C. R. Stauffer
S. Taber
A. C. Trowbridge
W. H. Twenhofel
W. A. Tarr
J. A. Udden
J. B. Umpleby
F. R. Van Horn
T. W. Vaughan
T. L. Walker
H. S. Washington
T. L. Watson
S. Weidman
S. Weller
E. T. Wherry
David White
I. C. White
F. A. Wilder
M. Y. Williams
B. Willis
H. V. Winchell
G. F. Wright

FELLOWS-ELECT

F. J. Alcock
H. L. Alling
E. L. Bruce
W. H. Bucher
G. H. Cady
J. H. Hance
S. Powers
W. E. Pratt

There were also 93 visitors registered.

CONSTITUTION AND BY-LAWS

REFERENCE TO ADOPTION AND CHANGES

The provisional Constitution under which the Society was organized was approved August 15, 1888, and adopted December 27, 1888 (see Bulletin, volume 1, pages 7-8). These rules were elaborated and the revised Constitution and By-Laws were adopted December 27, 1889 (volume 1, pages 536, 571-578).

Several minor changes have been made in these rules, which are on record in the Bulletin as follows: Changes in the Constitution: December, 1894, volume 6, page 432; December, 1897, volume 9, page 400; December, 1909, volume 21, page 19; December, 1920, volume 32, page 94. Changes in the By-Laws: December, 1891, volume 3, page 470; December, 1893, volume 5, pages 553-554; December, 1894, volume 6, page 432; December, 1903, volume 14, page 535; December, 1909, volume 21, page 19; December, 1920, volume 32, page 99.

CONSTITUTION

Article I

NAME

This Society shall be known as THE GEOLOGICAL SOCIETY OF AMERICA.

Article II

OBJECT

The object of this Society shall be the promotion of the Science of Geology in North America.

Article III

MEMBERSHIP

The Society shall be composed of Fellows, Correspondents, and Patrons.

1. Fellows shall be persons who are engaged in geological work or in teaching geology.

Fellows admitted without election under the provisional Constitution shall be designated as Original Fellows on all lists or catalogues of the Society.

2. Correspondents shall be persons distinguished for their attainments in Geological Science and not residents in North America.

3. Patrons shall be persons who have bestowed important favors upon the Society.

4. Fellows alone shall be entitled to vote or hold office in the Society.

Article IV

OFFICERS

1. The officers of the Society shall consist of a President, a First Vice-President, a Second Vice-President, and one Vice-President to represent each of the

societies affiliated with this Society, a Secretary, a Treasurer, an Editor, and six Councilors.

These officers, together with the Presidents for the next preceding three years, shall constitute an Executive Committee, which shall be called the Council.

2. The President shall discharge the usual duties of a presiding officer at all meetings of the Society and of the Council. He shall take cognizance of the acts of the Society and of its officers, and cause the provisions of the Constitution and By-Laws to be faithfully carried into effect.

3. The First Vice-President shall assume the duties of President in case of the absence or disability of the latter. The Second Vice-President shall assume the duties of President in case of the absence or disability of both the President and First Vice-President. The Third Vice-President shall assume the duties of President in case of the absence or disability of the President and the First and Second Vice-Presidents.

4. The Secretary shall keep the records of the proceedings of the Society, and a complete list of the Fellows, with the dates of their election and disconnection with the Society. He shall also be the secretary of the Council.

The Secretary shall cooperate with the President in attention to the ordinary affairs of the Society. He shall attend to the preparation, printing and mailing of circulars, blanks and notifications of elections and meetings. He shall superintend other printing ordered by the Society or by the President, and shall have charge of its distribution, under the direction of the Council.

The Secretary, unless other provisions be made, shall also act as Editor of the publications of the Society, and as Librarian and Custodian of the property.

5. The Treasurer shall have the custody of all funds of the Society. He shall keep account of receipts and disbursements in detail, and this shall be audited as hereinafter provided.

6. The Editor shall supervise all matters connected with the publication of the transactions of the Society under the direction of the Council.

7. The Council is clothed with executive authority and with the legislative powers of the Society in the intervals between its meetings; but no extraordinary act of the Council shall remain in force beyond the next following stated meeting without ratification by the Society. The Council shall have control of the publications of the Society, under provisions of the By-Laws and of resolutions from time to time adopted. They shall receive nominations for Fellows, and, on approval by them, shall submit such nominations to the Society for action. They shall have power to fill vacancies *ad interim* in any of the offices of the Society.

8. *Terms of office.*—The President and Vice-Presidents shall be elected annually, and shall not be eligible to re-election more than once until after an interval of three years after retiring from office.

The Secretary, Treasurer, and Editor shall be eligible to re-election without limitation.

The term of office of the Councilors shall be three years; and these officers shall be so grouped that two shall be elected and two retire each year. Councilors retired shall not be re-eligible till after the expiration of a year.

Article V

VOTING AND ELECTIONS

1. All elections shall be by ballot. To elect a Fellow, Correspondent or Patron, or impose any special tax, shall require the assent of nine-tenths of all Fellows voting.

2. Voting by letter may be allowed.

3. *Election of Fellows.*—Nominations for fellowship may be made by two Fellows according to a form to be provided by the Council. One of these Fellows must be personally acquainted with the nominee and his qualifications for membership. The Council will submit the nominations received by them, if approved, to a vote of the Society in the manner provided in the By-Laws. The result may be announced at any stated meeting; after which notice shall be sent out to Fellows elect.

4. *Election of officers.*—Nominations for office shall be made by the Council. The nominations shall be submitted to a vote of the Society in the same manner as nominations for fellowship. The results shall be announced at the Annual Meeting; and the officers thus elected shall enter upon duty at the adjournment of the meeting.

Article VI

MEETINGS

1. The Society shall hold at least one stated meeting a year, in the winter season. The date and place of the Winter Meeting shall be fixed by the Council, and announced each year within three months after the adjournment of the preceding Winter Meeting. The program of each meeting shall be determined by the Council, and announced beforehand, in its general features. The details of the daily sessions shall also be arranged by the Council.

2. The Winter Meeting shall be regarded as the Annual Meeting. At this, elections of officers shall be declared, and the officers elect shall enter upon duty at the adjournment of the meeting.

3. Special meetings may be called by the Council, and must be called upon the written request of twenty Fellows.

4. Stated meetings of the Council shall be held coincidently with the stated meetings of the Society. Special meetings may be called by the President at such times as he may deem necessary.

5. *Quorum.*—At meetings of the Society a majority of those registered in attendance shall constitute a quorum. Five shall constitute a quorum of the Council.

Article VII

PUBLICATION

The serial publications of the Society shall be under the immediate control of the Council.

Article VIII

SECTIONS

Any group of Fellows representing a particular branch of geology may, with consent of the Council, organize as a section of the Society with separate con-

stitution and by-laws, provided that nothing in such constitution and by-laws conflict with the Constitution and By-Laws of the Geological Society of America, in letter or spirit, and provided that such constitution and by-laws and all amendments thereto shall have been approved by the Council.

Article IX

AMENDMENTS

1. This Constitution may be amended at any annual meeting by a three-fourths vote of all the Fellows, provided that the proposed amendment shall have been submitted in print to all Fellows at least three months previous to the meeting.

2. By-laws may be made or amended by a majority vote of the Fellows present and voting at any annual meeting, provided that printed notice of the proposed amendment or by-law shall have been given to all Fellows at least three months before the meeting.

BY-LAWS

Chapter I

OF MEMBERSHIP

1. No person shall be accepted as a Fellow unless he pay his initiation fee, and the dues for the year, within three months after notification of his election. The initiation fee shall be ten (10) dollars and the annual dues ten (10) dollars, the latter payable on or before the annual meeting in advance; but a single prepayment of one hundred fifty (150) dollars shall be accepted as commutation for life. A Fellow in good standing, however, who has paid annual dues for not less than fifteen (15) years may commute further dues and become a Life Fellow by making a single payment of one hundred (100) dollars.

2. The sums paid in commutation of dues shall be covered into the Publication Fund.

3. An arrearage in payment of annual dues shall deprive a Fellow of the privilege of taking part in the management of the Society and of receiving the publications of the Society. An arrearage continuing over two (2) years shall be construed as notification of withdrawal.

4. Any person eligible under Article III of the Constitution may be elected Patron upon the payment of one thousand (1,000) dollars to the Publication Fund of the Society.

Chapter II

OF OFFICIALS

1. The President shall countersign, if he approve, all duly authorized accounts and orders drawn on the Treasurer for the disbursement of money.

2. The Secretary, until otherwise ordered by the Society, shall perform the duties of Editor, Librarian, and Custodian of the property of the Society.

3. The Society may elect an Assistant Secretary.

4. The Treasurer shall give bonds, with two good sureties approved by the Council, in the sum of five thousand dollars, for the faithful and honest performance of his duties and the safe-keeping of the funds of the Society. He may deposit the funds in bank at his discretion, but shall not invest them without authority of the Council. His accounts shall be balanced as on the thirtieth day of November of each year.

5. In the selection of Councilors the various sections of North America shall be represented as far as practicable.

6. The minutes of the proceedings of the Council shall be subject to call by the Society.

7. The Council may transact its business by correspondence during the intervals between its stated meetings; but affirmative action by a majority of the Council shall be necessary in order to make action by correspondence valid.

Chapter III

OF ELECTION OF MEMBERS

1. Nominations for fellowship may be proposed at any time on blanks to be supplied by the Secretary.

2. The *form* for the nomination of Fellows shall be as follows:

In accordance with his desire, we respectfully nominate for Fellow of the Geological Society of America:

Full name; degrees; address; occupation; branch of Geology now engaged in, work already done and publications made.

(Signed by at least two Fellows.)

The form when filled is to be transmitted to the Secretary.

3. The Secretary will bring all nominations before the Council, and the Council will signify its approval or disapproval of each.

4. At least a month before one of the stated meetings of the Society the Secretary will mail a printed list of all approved nominees to each Fellow, accompanied by such information as may be necessary for intelligent voting; but an informal list of the candidates shall be sent to each Fellow at least two weeks prior to distribution of the ballots.

5. The Fellows receiving the list will signify their approval or disapproval of each nominee, and return the lists to the Secretary.

6. At the next stated meeting of the Council the Secretary will present the lists and the Council will canvass the returns.

7. The Council, by unanimous vote of the members in attendance, may still exercise the power of rejection of any nominee whom new information shows to be unsuitable for fellowship.

8. At the next stated meeting of the Society the Council shall declare the results.

9. Correspondents and Patrons shall be nominated by the Council, and shall be elected in the same manner as Fellows.

Chapter IV

OF ELECTION OF OFFICERS

1. The Council shall prepare a list of nominations for the several offices, which list will constitute the regular ticket. The ticket must be approved by a majority of the entire Council. The nominee for President shall not be a member of the Council. The nominee for Third Vice-President shall be the nominee for the presidency of the Paleontological Society, which has been organized as a section under Article VIII of the Constitution. The nominee for the vice-president representing an affiliated society shall be chosen from the joint fellowship by vote of the affiliated society concerned, subject to confirmation by the Council of the Geological Society of America.

2. The list shall be mailed to the Fellows, for their information, at least nine months before the Annual Meeting. Any five Fellows may forward to the Secretary other nominations for any or all offices. All such nominations reaching the Secretary at least 40 days before the Annual Meeting shall be printed, together with the names of the nominators, as special tickets. The regular and special tickets shall then be mailed to the Fellows at least 25 days before the Annual Meeting.

3. The Fellows will send their ballots to the Secretary in double envelopes, the outer envelope bearing the voter's name. At the Winter Meeting of the Council, the Secretary will bring the returns of ballots before the Council for canvass, and during the Winter Meeting of the Society the Council shall declare the result.

4. In case a majority of all the ballots shall not have been cast for any candidate for any office, the Society shall by ballot at such Winter Meeting proceed to make an election for such office from the two candidates having the highest number of votes.

Chapter V

OF FINANCIAL METHODS

1. No pecuniary obligation shall be contracted without express sanction of the Society or the Council. But it is to be understood that all ordinary, incidental, and running expenses have the permanent sanction of the Society, without special action.

2. The creditor of the Society must present to the Treasurer a fully itemized bill, certified by the official ordering it, and approved by the President. The Treasurer shall then pay the amount out of any funds not otherwise appropriated, and the receipted bill shall be held as his voucher.

3. At each annual meeting, the President shall call upon the Society to choose two Fellows, not members of the Council, to whom shall be referred the books of the Treasurer, duly posted and balanced to the close of November thirtieth, as specified in the By-Laws, Chapter II, clause 4. The Auditors shall examine the accounts and vouchers of the Treasurer, and any member or members of the Council may be present during the examination. The report of the Auditors shall be rendered to the Society before the adjournment of the meeting, and the Society shall take appropriate action.

Chapter VI

OF PUBLICATIONS

1. The publications are in charge of the Council and under its control.

2. One copy of each publication shall be sent to each Fellow, Correspondent, and Patron, and each author shall receive thirty (30) copies of his memoir.

Chapter VII

OF THE PUBLICATION FUND

1. The Publication Fund shall consist of donations made in aid of publication, and of the sums paid in commutation of dues, according to the By-Laws, Chapter I, clause 2.

2. Donors to this fund, not Fellows of the Society, in the sum of two hundred dollars, shall be entitled, without charge, to the publications subsequently appearing.

Chapter VIII

OF ORDER OF BUSINESS

1. The Order of Business at Winter Meetings shall be as follows:
   (1) Call to order by the presiding officer.
   (2) Introductory ceremonies.
   (3) Report of the Council (including reports of the officers).
   (4) Appointment of the Auditing Committee.
   (5) Declaration of the vote for officers, and election by the meeting in case of failure to elect by the Society through transmitted ballots.
   (6) Declaration of the vote for Fellows.
   (7) Deferred business.
   (8) New business.
   (9) Announcements.
   (10) Necrology.
   (11) Reading of scientific papers.

2. At an adjourned session the order shall be resumed at the place reached on the previous adjournment, but new business will be in order before the reading of scientific papers.

3. At the Summer Meeting the items of business under numbers (3), (4), (5), (10) shall be omitted.

4. At any Special Meeting the order of business shall be numbers (1), (2), (3), (9), followed by the special business for which the meeting was called.

PUBLICATION RULES

(Adopted by the Council April 21, 1891; Revised April 30, 1894, May, 1904, February 5, 1910, and December 27, 1920)

General Provisions

Section 1. The Council shall annually appoint from their own number a Publication Committee, consisting of the Secretary, the Treasurer, the Editor, and two others, whose duties shall be to determine the disposition of matter offered for publication, except as provided in section 12; to determine the expediency, in view of the financial condition of the Society, of publishing any matter accepted on its merits; to exercise general oversight of the matter and manner of publication; to determine the share of the cost of publication (including illustrations) to be borne by the author when it becomes necessary to divide cost between the Society and the author; to adjudicate any questions relating to publication that may be raised from time to time by the Editor or by the Fellows of the Society; and in general to act for the Council in all matters pertaining to publication. (Cons., Art. IV, 7; Art. VII; By-Laws, chap. VI.)

2. The duties of the Editor are to receive material offered for publication; to examine and submit it, with estimates of cost, to the Publication Committee; to publish all material accepted by the Council or Publication Committee; to revise proofs in connection with authors; to prepare lists of contents and general indexes; to audit bills for printing and illustrating; and to perform all other duties connected with publication not assigned to other officers. (Cons., Art. IV, 6; Rules, Sec. 16.)

3. The duties of the Secretary include the preparation of a record of the proceedings of each meeting of the Society in form for publication, and the custody, distribution, sale, exchange or other authorized disposition of the publications. (Cons., Art. IV, 4; By-Laws, chap. II, 2.)

4. Special committees may be appointed by the Council or the Publication Committee to examine and report on any matter offered for publication. (Rules, Sec. 11.)

The Bulletin

Title and General Character

5. The Society shall publish a serial record of its work entitled "Bulletin of the Geological Society of America."

6. The Bulletin shall be published in quarterly parts, consecutively paged for each volume. The parts shall be suitably designated and each shall bear a title setting forth the contents and authorship, the seal and imprint of the Society and the date of publication.

7. The closing quarterly part of each volume shall contain an index, paged consecutively with the body of the volume; and it shall be accompanied by a volume title-page and lists of contents and illustrations, together with lists of

the publications of the Society and such other matter as the Publication Committee may deem necessary, all arranged under Roman pagination.

MATTER OF THE BULLETIN

8. The matter published in the Bulletin shall comprise (1) communications presented at meetings by title or otherwise; (2) communications or memoirs not presented before the Society; (3) abstracts of papers read before the Society, prepared or revised for publication by authors; (4) reports of discussions held before the Society, prepared or revised for publication by authors; (5) proceedings of the meetings of the Society prepared by the Secretary; (6) plates, maps, and other illustrations necessary for the proper understanding of communications; (7) lists of Officers and Fellows, Constitution, By-Laws, resolutions of permanent character, rules relating to procedure, to publication, and to other matters, etcetera, and (8) indexes, title-pages, and lists of contents for each volume.

9. Abstracts, reports of discussion, or other matter purporting to emanate from any author shall not be published unless prepared or revised by the author.

10. Manuscript designed for publication in the Bulletin must be complete as to copy for text and illustration, except by special arrangement between the author and the Council or Publication Committee; it must be perfectly legible (preferably typewritten) and preceded by a table of contents (section 15). The cost of necessary revision of copy or reconstruction of illustrations shall be assessed on the author.

11. The Editor shall examine matter designated for publication, and shall prepare an itemized estimate of the cost of publication and convey the whole to the Publication Committee. The Publication Committee shall then scrutinize the communication with reference, first, to relevancy; second, to scientific value; third, to literary character, and, fourth, to cost of publication, including revision. For advice with reference to the relevancy, scientific value, and literary character of any communication the Publication Committee may refer it to a special committee of their own number or of the Society at large or may call to their aid from outside one or more experts. Questions of disagreement between the Editor and authors shall be referred to the Publication Committee and appeal may be taken to the Council.

12. Communications from non-fellows shall be published only by specific authority from the Council.

13. Communications from Fellows not presented at regular meetings of the Society shall be published only upon unanimous vote of the Publication Committee, except by specific authority from the Council.

14. Matter offered for publication becomes thereby the property of the Society, and shall not be published elsewhere prior to publication in the Bulletin, except by consent of the Publication Committee.

DETAILS OF THE BULLETIN

15. The matter of each memoir shall be classified by subjects, and the classification suitably indicated by subtitles; and a list of contents shall be arranged; and such memoir may, at the option of the Publication Committee, contain an alphabetical index, provided the author prepare and pay for it.

16. Proofs of text and illustrations shall be submitted to authors whenever practicable; but printing shall not be delayed by reason of absence or incapacity of authors more than one week beyond the time required for transmission by mail. Complete proofs of the proceedings of meetings shall be sent to the Secretary, and proofs of papers and abstracts contained therein and exceeding one-half page in length shall be sent also to authors.

17. The cost of proof corrections in excess of ten per cent on the cost of printing may be charged to authors.

18. Unless the author of a memoir objects thereto, the discussion upon his communication shall be printed at the end thereof, with a suitable reference in the list of contents. In case the author objects to this arrangement, the discussion shall be printed in the closing number of the volume.

19. The author of each memoir occupying four pages or more of text in the body of the Bulletin shall receive 40 "separates" without charge, and may order through the Editor any edition of exactly similar separates at an advance of ten per cent on the cost of paper, presswork and binding; and no author's separates of such memoirs shall be issued except in this regular form.

20. Authors of papers, abstracts, or discussions less than four printed pages in length may order, through the Editor, at an advance of ten per cent on the cost of paper, presswork, binding and necessary composition, any number of extra copies, provided they bear the original pagination and a printed reference to the serial and volume from which they are extracted.

21. The Editor shall keep a record of all publications issued wholly or in part under the auspices of the Society, whether they be author's editions of memoirs, author's extracts from proceedings, or any other matter printed from type originally composed for the Bulletin.

DIRECTIONS TO PRINTER

22. Each memoir of the Bulletin shall begin, under its proper title, on an odd-numbered page bearing at its head the title of the serial, the volume number, the part number, the limiting pages, the plates, and the date of publication, together with a list of contents. Each memoir shall be accompanied by the illustrations pertaining to it, the plates numbered consecutively for the volume.

23. The author's separates of each memoir shall be enclosed in a cover bearing at the head of its title-page the title of the serial, the volume number, the limiting pages, and the numbers of the contained plates; in its upper-central part a title indicating the contents and authorship; in its lower-central part the seal of the Society; and at the bottom the imprint of the Society. (See also sections 19 and 20.)

24. The bottom of each signature and each initial page will bear a signature mark giving an abbreviated title of the serial, the volume, and the year; and every page (except volume title-page) shall be numbered, the initial and subtitle pages in parentheses at bottom.

25. The page-head titles shall be: on even-numbered pages, name of author and catch title of paper; on odd-numbered pages, catch title to contents of page.

26. The date of publication of each brochure shall be the day upon which the last form is locked and put on the press.

27. The type used in printing the Bulletin shall be as follows: For memoirs, body, long primer, 6-to-pica leads; extracts, brevier, 8-to-pica leads; footnotes, nonpareil, set solid; titles, long primer caps, with small caps for author's name; subtitles, long primer caps, small caps, italic, etcetera, as far as practicable; for designation of cuts, nonpareil caps and italics, and for legends, nonpareil, Roman, set solid; for lists of contents of brochures, brevier, 6-to-pica leads, a new line to an entry, running indentation; for volumes, the same, except 4-to-pica leads and names of authors in small caps; for indexes, nonpareil, set solid, double column, leaders, catch words in small caps, with spaces between initial letters. For serial titles, on initial pages, brevier block caps, with corresponding small caps for volume designation, etcetera; on covers, the same, except for page heads long primer caps; for serial designation, long primer; for brochure designation, pica caps; special title and author's name, etcetera, long primer and brevier caps; no frame on cover. No change in type shall be made to adjust matter to pages.

28. Volumes, plates, and cuts in text shall be numbered in Arabic; Roman numeration shall be used only in signature marks, and in paging the lists of contents, etcetera, arranged for binding at the beginning of the volume.

29. Imprimatur of Editor, on volume title-page; imprimatur of Council and Publication Committee, on obverse of volume title-page; imprimatur of Secretary, on initial pages and covers of brochures of proceedings. Printer's card, in fine type on obverse of title-page.

30. The paper shall be for body of volume, 70-pound toned paper, folding to 16 x 25 centimeters; for plates, good quality plate paper, smooth-surfaced, white, cut to 6½ x 10 inches for single plates; for covers smooth-surfaced, fine quality 70-pound light-buff manila paper.

31. The sheets of the brochures shall be stitched with thread; single page plates shall be stitched with the sheets of the brochure; folding plates may be either gummed or stitched (mounted on stubs if necessary); covers shall be gummed.

EDITION, DISTRIBUTION, AND PRICE

32. The regular edition shall be 750 copies in the regular quarterly form and 50 copies separately in covers of each memoir occupying four pages or more of text. Each author of a memoir occupying not less than four pages of text shall receive 40 copies of his memoir gratis. If two or more authors contribute to a memoir brochure of four pages or more in length, the edition shall be enlarged so as to give each author 40 copies. (By-Laws, chap. VI, 2.)

33. The undistributed residue of separates shall be held for sale.

34. The Bulletin shall be sent free to Fellows of the Society not in arrears for dues, and also to exchanging institutions. (By-Laws, chap. I, 3.)

35. The price of the Bulletin shall be as follows: To Fellows, libraries, and institutions, and to individuals not residing in North America, $9 per volume; to individuals residing in North America and who are not Fellows, $10. The price of each brochure shall be a multiple of five cents, and shall be, to Fellows, one cent per page plus three cents per plate, and to the public an advance of fifty per cent on the price to Fellows. The prices of the separate brochures and of the quarterly parts may be found in the front of each volume.

OFFICERS, CORRESPONDENTS, AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

OFFICERS FOR 1921

President:

James F. Kemp, New York City

Vice-Presidents:

J. B. Woodworth, Cambridge, Mass.
Arthur Keith, Washington, D. C.
T. W. Stanton, Washington, D. C.
Charles Palache, Cambridge, Mass.

Secretary:

Edmund Otis Hovey, American Museum of Natural History, New York, N. Y.

Treasurer:

Edward B. Mathews, Johns Hopkins University, Baltimore, Md.

Editor:

J. Stanley-Brown, 26 Exchange Place, New York, N. Y.

Councilors:

(Term expires 1921)

William S. Bayley, Urbana, Ill.
Eugene W. Shaw, Washington, D. C.

(Term expires 1922)

T. W. Vaughan, Washington, D. C.
George F. Kay, Iowa City, Iowa

(Term expires 1923)

L. C. Graton, Cambridge, Mass.
G. D. Louderback, Berkeley, Calif.

MEMBERSHIP, 1920

CORRESPONDENTS

BARROIS, CHARLES, Lille, France. December, 1909.
BRÖGGER, W. C., Christiania, Norway. December, 1909.
CAPELLINI, GIOVANNI, Bologna, Italy. December, 1910.
DE GEER, BARON GERHARD, Stockholm, Sweden. December, 1910.
GEIKIE, SIR ARCHIBALD, Hasslemere, England. December, 1909.
HEIM, ALBERT, Zürich, Switzerland. December, 1909.
KAYSER, EMANUEL, Marburg, Germany. December, 1909.
KILIAN, W., Grenoble, France. December, 1912.
TEALL, J. J. H., London, England. December, 1912.
TIETZE, EMIL, Vienna, Austria. December, 1910.

FELLOWS

* Indicates Original Fellows (see article III of Constitution)

ABBE, CLEVELAND, JR., 625 So. Broadway, Yonkers, N. Y. August, 1899.
ADAMS, FRANK DAWSON, McGill University, Montreal, Canada. Dec., 1889.
ADAMS, GEORGE I., University of Alabama, Tuscaloosa, Ala. December, 1902.
ALCOCK, F. J., Geological Survey of Canada, Ottawa, Canada. Dec., 1920.
ALDEN, WILLIAM C., U. S. Geological Survey, Washington, D. C. Dec., 1909.
ALDRICH, TRUMAN H., 1026 Glen Iris Ave., Birmingham, Ala. May, 1889.
ALLAN, JOHN A., University of Alberta, Strathcona, Canada. December, 1914.
ALLEN, R. C., 1001 Kirby Building, Cleveland, Ohio. December, 1911.
ALLING, H. L., University of Rochester, Rochester, N. Y. December, 1920.
AMI, HENRY M., Strathcona Park, Ottawa, Canada. December, 1889.
ANDERSON, FRANK M., State Mining Bureau, 2604 Aetna St., Berkeley, Calif. December, 1902.
ANDERSON, ROBERT V., 47 Parliament St., London, S. W., England. Dec., 1911.
ANDREWS, E. C., Geol. Surv. of N. S. W., Sydney, N. S. Wales. Dec., 1920.
ARNOLD, RALPH, 25 Broad St., New York City. December, 1904.
ASHLEY, GEORGE HALL, State Capitol, Harrisburg, Pa. August, 1895.
ATWOOD, WALLACE WALTER, Clark University, Worcester, Mass. Dec., 1909.
BAGG, RUFUS MATHER, JR., 7 Brokaw Place, Appleton, Wis. December, 1896.
BAIN, H. FOSTER, 1923 35th St. N. W., Washington, D. C. December, 1895.
BAKER, MANLEY BENSON, School of Mining, Kingston, Ontario. Dec., 1911.
BALDWIN, S. PRENTISS, 2930 Prospect Ave., Cleveland, Ohio. August, 1895.
BALL, SYDNEY H., 71 Broadway, New York City. December, 1905.
BANCROFT, JOSEPH A., McGill University, Montreal, Canada. December, 1914.
BARBOUR, ERWIN HINCKLEY, University of Nebraska, Lincoln, Neb. Dec., 1896.
BARTON, GEORGE H., Boston Society of Natural History, Boston, Mass. August, 1890.
BARTSCH, PAUL, U. S. National Museum, Washington, D. C. December, 1917.
BASCOM, FLORENCE, Bryn Mawr College, Bryn Mawr, Pa. August, 1894.
BASSLER, RAY SMITH, U. S. National Museum, Washington, D. C. Dec., 1906.
BASTIN, EDSON S., U. S. Geological Survey, Washington, D. C. Dec., 1909.
BATEMAN, ALAN MARA, Yale University, New Haven, Conn. December, 1916.
BAYLEY, WILLIAM S., University of Illinois, Urbana, Ill. December, 1888.

Beede, Joshua W., 404 West 38th St., Austin, Texas. December, 1902.
Benson, W. N., University of Otago, Dunedin, New Zealand. Dec., 1919.
Berkey, Charles P., Columbia University, New York, N. Y. August, 1901.
Berry, Edward Wilber, Johns Hopkins University, Baltimore, Md. Dec., 1909.
Beyer, Samuel Walker, Iowa Agricultural College, Ames, Iowa. Dec., 1896.
Blackwelder, Eliot, 317 Railway Exchange Bldg., Denver, Colo. Dec., 1908.
Boutwell, John M., Nat. Copper Bank, Salt Lake City, Utah. Dec., 1905.
Bowen, Charles F., c/o Carter Oil Co., 26 Broadway, N. Y. City. Dec., 1916.
Bowen, N. L., Queen's University, Kingston, Ont., Canada. December, 1917.
Bowie, William, U. S. Coast and Geodetic Survey, Washington, D. C. December, 1919.
Bownocker, John Adams, Ohio State University, Columbus, Ohio. Dec., 1904.
*Branner, John C., Leland Stanford, Jr., University, Stanford Univ., Calif.
Branson, Edwin Bayer, University of Missouri, Columbia, Mo. Dec., 1911.
Bretz, J. H., University of Chicago, Chicago, Ill. December, 1917.
Brigham, Albert Perry, Colgate University, Hamilton, N. Y. December, 1893.
Brock, Reginald W., Univ. of British Columbia, Vancouver, B. C. Dec., 1904.
Brokaw, A. D., 157 Maplewood Ave., Maplewood, N. J. December, 1920.
Brooks, Alfred Hulse, U. S. Geological Survey, Washington, D. C. Aug., 1899.
Brown, Barnum, American Museum of Natural History, New York, N. Y. December, 1910.
Brown, Charles Wilson, Brown University, Providence, R. I. Dec., 1908.
Brown, Thomas Clachar, Laurel Bank Farm, Fitchburg, Mass. Dec., 1915.
Bruce, E. L., Geological Survey of Canada, Ottawa, Canada. Dec., 1920.
Bucher, W. H., University of Cincinnati, Cincinnati, Ohio. December, 1920.
Buddington, A. F., Brown University, Providence, R. I. December, 1919.
Buehler, Henry Andrew, Rolla, Mo. December, 1909.
Burchard, E. F., U. S. Geological Survey, Washington, D. C. December, 1920.
Burling, Lancaster D., Whitehall Petr. Corp., 53 Parliament St., Westminster, S. W. I., London, England. December, 1917.
Burwash, Edward M. J., University of Manitoba, Winnipeg, Canada. December, 1916.
Butler, Bert S., Box 277, Calumet, Mich. December, 1912.
Butler, G. Montague, College of Mines, Tucson, Arizona. December, 1911.
Butts, Charles, U. S. Geological Survey, Washington, D. C. December, 1912.
Buwalda, J. P., Yale University, New Haven, Conn. December, 1920.
Cady, G. H., Fayetteville, Ark. December, 1920.
Calhoun, Fred Harvey Hall, Clemson College, S. C. December, 1909.
Calkin, Frank C., U. S. Geological Survey, Washington, D. C. Dec., 1914.
Campbell, Henry D., Washington and Lee Univ., Lexington, Va. May, 1889.
Campbell, Marius R., U. S. Geological Survey, Washington, D. C. Aug., 1892.
Campos, Luiz Filippe G. de, Geological Survey of Brazil, Rio de Janeiro, Brazil. December, 1917.
Camsell, Charles, Department of Mines, Ottawa, Canada. December, 1914.
Capps, Stephen R., Jr., U. S. Geological Survey, Washington, D. C. Dec., 1911.
Carman, J. Ernest, Ohio State University, Columbus, Ohio. December, 1917.
Carney, Frank, 208 S. Chatauqua St., Wichita, Kans. December, 1908.
Case, Ermine C., University of Michigan, Ann Arbor, Mich. December, 1901.
Chadwick, George H., University of Rochester, Rochester, N. Y. Dec., 1911.

CHAMBERLIN, ROLLIN T., University of Chicago, Chicago, Ill. December, 1913.
*CHAMBERLIN, T. C., University of Chicago, Chicago, Ill.
CLAGHORN, CLARENCE RAYMOND, 22 Dover Road, Wellesley, Mass. Aug., 1891.
CLAPP, CHARLES H., Montana School of Mines, Butte, Mont. December, 1914.
CLAPP, FREDERICK G., 120 Broadway, New York, N. Y. December, 1905.
CLARK, BRUCE L., Bacon Hall, Univ. of California, Berkeley, Calif. Dec., 1918.
CLARK, F. R., U. S. Geological Survey, Washington, D. C. December, 1919.
CLARK, W. O., 771 Hamilton St., Palo Alto, Calif. December, 1920.
CLARKE, JOHN MASON, State Museum, Albany, N. Y. December, 1897.
CLELAND, HERDMAN F., Williams College, Williamstown, Mass. Dec., 1905.
CLEMENTS, J. MORGAN, 20 Broad St., New York City. December, 1894.
COBB, COLLIER, University of North Carolina, Chapel Hill, N. C. Dec., 1894.
COLEMAN, ARTHUR P., Toronto University, Toronto, Canada. December, 1896.
COLLIE, GEORGE L., Beloit College, Beloit, Wis. December, 1897.
COLLIER, ARTHUR J., U. S. Geological Survey, Washington, D. C. June, 1902.
CONDIT, D. DALE, c/o S. Pearson & Son, 47 Parliament St., London, England. December, 1916.
COOK, CHARLES W., University of Michigan, Ann Arbor, Mich. Dec., 1915.
COOKE, C. WYTHE, U. S. Geological Survey, Washington, D. C. Dec., 1918.
COSTE, EUGENE, 2208 Amherst St., Calgary, Alberta, Canada. Dec., 1906.
COX, G. H., School of Mines, Rolla, Mo. December, 1920.
CRAWFORD, RALPH DIXON, 1050 Tenth St., Boulder, Colo. December, 1916.
CROOK, ALJA R., State Museum of Natural History, Springfield, Ill. Dec., 1898.
*CROSBY, WILLIAM O., Massachusetts Institute of Technology, Boston, Mass.
CROSS, WHITMAN, 2138 Bancroft Place, Washington, D. C. May, 1889.
CULVER, GARRY E., 310 Center Ave., Stevens Point, Wis. December, 1891.
CUMINGS, EDGAR R., Indiana University, Bloomington, Ind. August, 1901.
*CUSHING, HENRY P., Western Reserve University, Cleveland, Ohio.
CUSHMAN, J. A., Sharon, Mass. December, 1919.
DAKE, C. L., Missouri School of Mines, Rolla, Mo. December, 1920.
DALE, N. C., Hamilton College, Clinton, N. Y. December, 1920.
DALY, REGINALD A., Harvard University, Cambridge, Mass. December, 1905.
DANA, EDWARD SALISBURY, Yale University, New Haven, Conn. Dec., 1908.
*DARTON, NELSON H., U. S. Geological Survey, Washington, D. C.
DAVIS, E. F., 1539 Bonita Ave., Berkeley, Calif. December, 1920.
*DAVIS, WILLIAM M., 31 Hawthorne St., Cambridge, Mass.
DAY, ARTHUR LOUIS, Geophysical Laboratory, Washington, D. C. Dec., 1909.
DAY, DAVID T., 1333 F St. N. W., Washington, D. C. August, 1891.
DEAN, BASHFORD, Columbia University, New York, N. Y. December, 1910.
DE GOLYER, E. L., 65 Broadway, New York City. December, 1918.
DEUSSEN, ALEXANDER, 504 Stewart Bldg., Houston, Texas. December, 1916.
DE WOLF, FRANK WILBRIDGE, Urbana, Ill. December, 1909.
DICKERSON, ROY E., c/o Pacific Commercial Co., Manila, P. I. Dec., 1918.
*DILLER, JOSEPH S., U. S. Geological Survey, Washington, D. C.
D'INVILLIERS, EDWARD V., 518 Walnut St., Philadelphia, Pa. December, 1888.
DODGE, RICHARD E., Dodge Farm, Washington, Conn. August, 1897.
DRAKE, NOAH FIELDS, Fayetteville, Arkansas. December, 1898.
DRESSER, JOHN A., 701 Eastern Townships Bank Bldg., Montreal, Canada. December, 1906.

*Dumble, Edwin T., 2003 Main St., Houston, Texas.

Dunbar, C. O., University of Minnesota, Minneapolis, Minn. December, 1920.

Eakle, Arthur S., University of California, Berkeley, Calif. December, 1899.

Eckel, Edwin C., Munsey Building, Washington, D. C. December, 1905.

Emery, Wilson B., Casper, Wyoming. December, 1919.

*Emerson, Benjamin K., Amherst, Mass.

Emmons, William H., Univ. of Minnesota, Minneapolis, Minn. Dec., 1912.

*Fairchild, Herman L., University of Rochester, Rochester, N. Y.

Farrington, Oliver C., Field Museum of Natural History, Chicago, Ill. December, 1895.

Fath, A. E., U. S. Geological Survey, Washington, D. C. December, 1920.

Fenneman, Nevin M., University of Cincinnati, Cincinnati, Ohio. Dec., 1904.

Fenner, Clarence N., Geophysical Laboratory, Washington, D. C. Dec., 1911.

Ferguson, H. G., U. S. Geological Survey, Washington, D. C. December, 1920.

Fisher, Cassius Asa, 705 First Natl. Bank Bldg., Denver, Colo. Dec., 1908.

Foerste, August F., 129 Wroe Ave., Dayton, Ohio. December, 1899.

Ford, William E., Sheffield Scientific School, New Haven, Conn. Dec., 1915.

Foye, W. G., Wesleyan University, Middletown, Conn. December, 1919.

Fuller, Myron L., 157 Spring St., Brockton, Mass. December, 1898.

Galloway, J. J., Columbia University, New York, N. Y. December, 1920.

Galpin, Sidney L., 630 Park Ave., Ames, Iowa. December, 1917.

Gane, Henry Stewart, Rural Del. No. 1, Santa Barbara, Calif. Dec., 1896.

Gardner, Julia A., U. S. Geological Survey, Washington, D. C. Dec., 1920.

Gardner, James H., 626 Kennedy Building, Tulsa, Okla. December, 1911.

George, Russell D., University of Colorado, Boulder, Colo. December, 1906.

Gill, Adam Capen, Cornell University, Ithaca, N. Y. December, 1888.

Glenn, L. C., Vanderbilt University, Nashville, Tenn. June, 1900.

Goldman, Marcus Isaac, U. S. Geol. Survey, Washington, D. C. Dec., 1916.

Goldthwait, James Walter, Dartmouth College, Hanover, N. H. Dec., 1909.

Gordon, Charles H., University Library, University of Tennessee, Knoxville, Tenn. August, 1893.

Gordon, Clarence E., Massachusetts Agricultural College, Amherst, Mass. December, 1913.

Gould, Charles N., 1218 Colcord Bldg., Oklahoma City, Okla. Dec., 1904.

Grabau, Amadeus W., Government University, Pekin, China. Dec., 1898.

Granger, Walter, American Museum of Natural History, New York, N. Y. December, 1911.

Grant, Ulysses Sherman, Northwestern Univ., Evanston, Ill. Dec., 1890.

Grasty, John Sharshall, Box 458, Charlottesville, Va. December, 1911.

Graton, Louis C., Foxcroft House, Cambridge, 38, Mass. December, 1913.

Gregory, Herbert E., Yale University, New Haven, Conn. August, 1901.

Greene, Frank Cook, 30 North Yorktown St., Tulsa, Okla. December, 1917.

Grimsley, George P., 16 York Court, Baltimore, Md. August, 1895.

Grout, Frank F., University of Minnesota, Minneapolis, Minn. Dec., 1918.

Gurley, William F. E. R., University of Chicago, Chicago, Ill. Dec., 1914.

Halberstadt, Baird, Pottsville, Pa. December, 1909.

Hance, J. H., 708 W. Washington Boulevard, Urbana, Ill. December, 1920.

Hancock, E. T., U. S. Geological Survey, Washington, D. C. December, 1919.

Harder, E. C., 1111 Harrison Building, Philadelphia, Pa. December, 1918.

HARES, C. J., the Ohio Oil Co., Casper, Wyo. December, 1920.
HARRIS, GILBERT D., Cornell University, Ithaca, N. Y. December, 1903.
HARRISON, JOHN BURCHMORE, Georgetown, British Guiana. June, 1902.
HARTNAGEL, CHRIS A., Education Building, Albany, N. Y. December, 1913.
HASTINGS, JOHN B., 4209 Council St., Los Angeles, Calif. May, 1889.
*HAWORTH, ERASMUS, University of Kansas, Lawrence, Kans.
HAYES, ALBERT O., Geological Survey of Canada, Ottawa, Canada. Dec., 1919.
HEALD, K. C., U. S. Geological Survey, Washington, D. C. December, 1920.
HENNEN, RAY V., 1701 Benedum-Trees Bldg., Pittsburgh, Pa. December, 1914.
HERSHEY, OSCAR H., Crocker Building, San Francisco, Calif. December, 1909.
HEWETT, DONNEL F., U. S. Geological Survey, Washington, D. C. Dec., 1916.
HICE, RICHARD R., Beaver, Pa. December, 1903.
HILL, J. M., U. S. Geological Survey, Washington, D. C. December, 1920.
*HILL, ROBERT T., 612 American Exchange Bldg., Dallas, Texas.
HILLS, RICHARD C., Denver, Colo. August, 1894.
HINDS, HENRY, Sinclair Oil and Gas Company, Tulsa, Okla. December, 1912.
HINTZE, FERDINAND FRIIS, 580 Corona St., Denver, Colo. December, 1917.
HOBBS, WILLIAM H., University of Michigan, Ann Arbor, Mich. August, 1891.
*HOLBROOK, LEVI, P. O. Box 536, New York, N. Y.
HOLDEN, ROY J., Virginia Polytechnic Institute, Blacksburg, Va. Dec., 191[illegible]
HOLLAND, WILLIAM JACOB, Carnegie Museum, Pittsburgh, Pa. December, 191[illegible]
HOLLICK, ARTHUR, N. Y. Botanical Garden, New York, N. Y. August, 1898.
HOPKINS, O. B., U. S. Geological Survey, Washington, D. C. December, 1919.
HOPKINS, THOMAS C., Syracuse University, Syracuse, N. Y. December, 1894.
HOTCHKISS, WILLIAM OTIS, State Geological Survey, Madison, Wis. Dec., 1911.
*HOVEY, EDMUND OTIS, American Museum of Natural History, New York, N. Y.
HOWE, ERNEST, Litchfield, Conn. December, 1903.
HUBBARD, GEORGE D., Oberlin College, Oberlin, Ohio. December, 1914.
HUDSON, GEORGE H., Plattsburg Normal School, Plattsburg, N. Y. Dec., 1917.
HUNT, WALTER F., University of Michigan, Ann Arbor, Mich. December, 1914.
HUNTINGTON, ELLSWORTH, Hopkins Hall, Yale University, New Haven, Conn. December, 1906.
HUSSAKOF, LOUIS, American Museum of Natural History, New York, N. Y. December, 1910.
HYDE, J. E., Western Reserve University, Cleveland, Ohio. December, 1916.
JACKSON, A. WENDELL, 9 Desbrosses St., New York, N. Y. December, 1888.
JACKSON, ROBERT T., Peterborough, N. H. August, 1894.
JAGGAR, THOMAS AUGUSTUS, JR., Hawaiian Volcano Observatory, Territory of Hawaii, U. S. A. December, 1906.
JEFFERSON, MARK S. W., Michigan State Normal College, Ypsilanti, Mich. December, 1904.
JEFFREY, EDWARD C., Harvard University, Cambridge, Mass. December, 1914.
JOHANNSEN, ALBERT, University of Chicago, Chicago, Ill. December, 1908.
JOHNSON, B. L., U. S. Geological Survey, Washington, D. C. December, 1919.
JOHNSON, DOUGLAS WILSON, Columbia University, New York, N. Y. Dec., 1906.
JOHNSON, ROSWELL H., 306 State Hall, University of Pittsburgh, Pittsburgh, Pa. December, 1918.
JOHNSTON, WILLIAM ALFRED, Geological Survey, Ottawa, Canada. Dec., 1916
KATZ, FRANK JAMES, U. S. Geological Survey, Washington, D. C. Dec., 191[illegible]

KAY, GEORGE FREDERICK, State Univ. of Iowa, Iowa City, Iowa. Dec., 1908.
KEITH, ARTHUR, U. S. Geological Survey, Washington, D. C. May, 1889.
*KEMP, JAMES F., Columbia University, New York, N. Y.
KEW, W. S. W., U. S. Geological Survey, Washington, D. C. December, 1920.
KEYES, CHARLES ROLLIN, 944 Fifth St., Des Moines, Iowa. August, 1890.
KINDLE, EDWARD M., Victoria Memorial Museum, Ottawa, Canada. Dec., 1905.
KIRK, CHARLES T., Box 1592, Tulsa, Okla. December, 1915.
KIRK, EDWIN, U. S. Geological Survey, Washington, D. C. December, 1912.
KNIGHT, CYRIL WORKMAN, Toronto, Ontario, Canada. December, 1911.
KNOPF, ADOLPH, Yale Station, New Haven, Conn. December, 1911.
KNOPF, ELEANORA BLISS, 105 East Rock Road, New Haven, Conn.
KNOWLTON, FRANK H., U. S. National Museum, Washington, D. C. May, 1889.
KRAUS, EDWARD HENRY, University of Michigan, Ann Arbor, Mich. June, 1902.
KÜMMEL, HENRY B., Trenton, N. J. December, 1895.
*KUNZ, GEORGE F., 401 Fifth Ave., New York, N. Y.
LAHEE, FREDERIC H., Sun Co., Dallas, Texas. December, 1917.
LANDES, HENRY, University of Washington, University Station, Seattle, Wash. December, 1908.
LANE, ALFRED C., Tufts College, Mass. December, 1889.
LARSEN, ESPER S., JR., U. S. Geological Survey, Washington, D. C. Dec., 1914.
LAWSON, ANDREW C., University of California, Berkeley, Cal. May, 1889.
LEE, WILLIS THOMAS, U. S. Geological Survey, Washington, D. C. Dec., 1903.
LEES, JAMES H., Iowa Geological Survey, Des Moines, Iowa. December, 1914.
LEITH, CHARLES K., University of Wisconsin, Madison, Wis. Dec., 1902.
LEONARD, ARTHUR G., State University of North Dakota, Grand Forks, N. Dak. December, 1901.
LEVERETT, FRANK, Ann Arbor, Mich. August, 1890.
LEWIS, JOSEPH VOLNEY, Rutgers College, New Brunswick, N. J. Dec., 1906.
LIBBEY, WILLIAM, Princeton University, Princeton, N. J. August, 1899.
LINDGREN, WALDEMAR, Massachusetts Institute of Technology, Cambridge, Mass. August, 1890.
LISBOA, MIGUEL A. R., Caixa postal 829, Ave. Rio Branco 46-V, Rio de Janeiro, Brazil. December, 1913.
LITTLE, HOMER P., c/o National Research Council, 1701 Massachusetts Ave., Washington, D. C. December, 1918.
LLOYD, E. R., Box 552, Augusta, Kans. December, 1919.
LOGAN, WILLIAM N., Indiana University, Bloomington, Ind. December, 1917.
LOOMIS, FREDERICK BREWSTER, Amherst College, Amherst, Mass. Dec., 1909.
LOUDERBACK, GEORGE D., University of California, Berkeley, Cal. June, 1902.
LOUGHLIN, GERALD F., U. S. Geological Survey, Washington, D. C. Dec., 1916.
LOW, ALBERT P., 154 McLaren St., Ottawa, Canada. December, 1905.
LULL, RICHARD SWANN, Yale University, New Haven, Conn. December, 1909.
LUPTON, CHARLES T., 611 17th St., Denver, Colo. December, 1916.
MCCALLIE, SAMUEL WASHINGTON, Atlanta, Ga. December, 1909.
MCCASKEY, HIRAM D., Central Point, Oregon. December, 1904.
MCCONNELL, RICHARD G., Geological and Natural History Survey of Canada, Ottawa, Canada. May, 1889.
MACDONALD, DONALD F., Sinclair Oil Company of Louisiana, Incorporated, Shreveport, La. December, 1915.

MACFARLANE, JAMES RIEMAN, Woodland Road, Pittsburgh, Pa. August, 1891.
MCINNES, WILLIAM, Geological and Natural History Survey of Canada, Ottawa, Canada. May, 1889.
MCKELLAR, PETER, Fort William, Ontario, Canada. August, 1890.
MANSFIELD, GEORGE R., 2067 Park Rd., N. W., Washington, D. C. Dec., 1909.
MARBUT, CURTIS F., Bureau of Soils, Washington, D. C. August, 1897.
MARSTERS, VERNON F., 219 Reliance Bldg., Kansas City, Mo. August, 1892.
MARTIN, GEORGE C., U. S. Geological Survey, Washington, D. C. June, 1902.
MARTIN, LAWRENCE, University of Wisconsin, Madison, Wis. December, 1909.
MATHER, KIRTLEY F., Denison University, Granville, Ohio. December, 1918.
MATHEWS, EDWARD B., Johns Hopkins University, Baltimore, Md. Aug., 1895.
MATSON, GEORGE C., Box 2044, Tulsa, Okla. December, 1918.
MATTHES, FRANCOIS E., U. S. Geol. Survey, Washington, D. C. Dec., 1914.
MATTHEW, W. D., American Museum of Natural History, New York, N. Y. December, 1903.
MAURY, CARLOTTA J., Hastings-on-Hudson, N. Y. December, 1920.
MAYNARD, THOMAS POOLE, 1622 D. Hurt Bldg., Atlanta, Ga. December, 1914.
MEAD, WARREN JUDSON, University of Wisconsin, Madison, Wis. Dec., 1916.
MEINZER, OSCAR E., U. S. Geological Survey, Washington, D. C. Dec., 1916.
MENDENHALL, WALTER C., U. S. Geol. Survey, Washington, D. C. June, 1902.
MERRIAM, JOHN C., Carnegie Institution, Washington, D. C. August, 1895.
MERRILL, GEORGE P., U. S. National Museum, Washington, D. C. Dec., 1888.
MERWIN, HERBERT E., Geophysical Laboratory, Washington, D. C. Dec., 1914.
MILLER, ARTHUR M., State University of Kentucky, Lexington, Ky. Dec., 1897.
MILLER, BENJAMIN L., Lehigh University, South Bethlehem, Pa. Dec., 1904.
MILLER, WILLET G., Toronto, Canada. December, 1902.
MILLER, WILLIAM JOHN, Smith College, Northampton, Mass. December, 1909.
MISER, HUGH D., U. S. Geological Survey, Washington, D. C. December, 1916.
MOFFIT, FRED HOWARD, U. S. Geological Survey, Washington, D. C. Dec., 1912.
MOLENGRAAF, G. A. F., Technical High School, Delft, Holland. December, 1913.
MOORE, ELWOOD S., Pennsylvania State College, State College, Pa. Dec., 1911.
MUNN, MALCOLM JOHN, Clinton Bldg., Tulsa, Okla. December, 1909.
*NASON, FRANK L., West Haven, Conn.
NELSON, W. A., Tennessee Geological Survey, Nashville, Tenn. Dec., 1920.
NEWLAND, DAVID HALE, Albany, N. Y. December, 1906.
NEWSOM, JOHN F., Leland Stanford, Jr., University, Stanford University, Calif. December, 1899.
NOBLE, LEVI F., Valyermo, Calif. December, 1916.
NORTON, WILLIAM H., Cornell College, Mount Vernon, Iowa. December, 1895.
NORWOOD, CHARLES J., State University, Lexington, Ky. August, 1894.
O'CONNELL, MARJORIE, 1939 Daly Ave., New York, N. Y. December, 1919.
OGILVIE, IDA HELEN, Barnard College, Columbia University, New York, N. Y. December, 1906.
O'HARA, CLEOPHAS C., South Dakota School of Mines, Rapid City, S. Dak. December, 1904.
OHERN, DANIEL WEBSTER, 515 W. 14th St., Oklahoma City, Okla. Dec., 1911.
OLIVEIRA, E. P. DE, Geol. Survey of Brazil, Rio de Janeiro, Brazil. Dec., 1918.
O'NEILL, J. J., Geological Survey of Canada, Ottawa, Canada. Dec., 1920.
OSBORN, HENRY F., American Museum of Natural History, New York, N. Y. August, 1894.

PACK, ROBERT W., American Exchange National Bank Bldg., Dallas, Texas. December, 1916.
PAIGE, SIDNEY, U. S. Geological Survey, Washington, D. C. December, 1911.
PALACHE, CHARLES, Harvard University, Cambridge, Mass. August, 1897.
PARKS, WILLIAM A., University of Toronto, Toronto, Canada. Dec., 1906.
*PATTON, HORACE B., 911 Foster Building, Denver, Colo.
PECK, FREDERICK B., Lafayette College, Easton, Pa. August, 1901.
PENROSE, RICHARD A. F., JR., 460 Bullitt Bldg., Philadelphia, Pa. May, 1889.
PERKINS, GEORGE H., University of Vermont, Burlington, Vt. June, 1902.
PERRY, JOSEPH H., 276 Highland St., Worcester, Mass. December, 1888.
PHALEN, WILLIAM C., The Solvay Process, Syracuse, N. Y. December, 1912.
PHILLIPS, ALEXANDER H., Princeton University, Princeton, N. J. Dec., 1914.
POGUE, JOSEPH E., 29 Fifth Ave., New York City. December, 1911.
POWERS, SIDNEY, Amerada Petr. Corp., Tulsa, Okla. December, 1920.
PRATT, JOSEPH H., North Carolina Geol. Survey, Chapel Hill, N. C. Dec., 1898.
PRATT, W. E., Humble Oil and Refining Co., Houston, Texas. Dec., 1920.
PRICE, WILLIAM A., JR., c/o Compania Transcontinental de Petroleo, S. A. Apartado 657, Tampico, Tamaulipas, Mexico. December, 1916.
PRINDLE, LOUIS M., U. S. Geological Survey, Washington, D. C. Dec., 1912.
PROUTY, WILLIAM F., Univ. of North Carolina, Chapel Hill, N. C. Dec., 1911.
*PUMPELLY, RAPHAEL, Newport, R. I.
RANSOME, FREDERICK L., U. S. Geol. Survey, Washington, D. C. August, 1895.
RAYMOND, PERCY EDWARD, Museum of Comparative Zoölogy, Cambridge, Mass. December, 1907.
REEDS, CHESTER A., American Museum of Natural History, New York, N. Y. December, 1913.
REGER, DAVID B., Box 816, Morgantown, W. Va. December, 1918.
REID, HARRY FIELDING, Johns Hopkins University, Baltimore, Md. Dec., 1892.
REINECKE, LEOPOLD, c/o P. A. Williams, Loanda, Angola, S. W. Africa. December, 1916.
RICE, WILLIAM NORTH, Wesleyan University, Middletown, Conn. August, 1890.
RICH, JOHN LYON, Box 294, Iola, Kans. December, 1912.
RICHARDS, R. W., U. S. Geological Survey, Washington, D. C. December, 1920.
RICHARDSON, CHARLES H., Syracuse University, Syracuse, N. Y. Dec., 1899.
RICHARDSON, GEORGE B., U. S. Geol. Survey, Washington, D. C. Dec., 1908.
RIES, HEINRICH, Cornell University, Ithaca, N. Y. December, 1893.
RIGGS, ELMER S., Field Museum of Natural History, Chicago, Ill. Dec., 1911.
ROBINSON, HENRY HOLLISTER, Hopkins Hall, New Haven, Conn. Dec., 1916.
RODDY, H. J., State Normal School, Millersville, Pa. December, 1919.
ROGERS, AUSTIN F., Stanford University, Calif. December, 1918.
ROSE, BRUCE, 38 Canada Life Bldg., Calgary, Alberta, Canada. Dec., 1916.
ROWE, JESSE PERRY, University of Montana, Missoula, Mont. December, 1911.
RUEDEMANN, RUDOLF, Albany, N. Y. December, 1905.
RUTLEDGE, JOHN JOSEPH, McAlester, Okla. December, 1911.
ST. JOHN, ORESTES H., 1141 Twelfth St., San Diego, Calif. May, 1889.
SALES, RENO H., Anaconda Copper Mining Company, Butte, Mon. Dec., 1916.
SAYLES, ROBERT WILCOX, Harvard University, Chestnut Hill, Mass. Dec., 1917.
*SALISBURY, ROLLIN D., University of Chicago, Chicago, Ill.
SARDESON, FREDERICK W., Univ. of Minnesota, Minneapolis, Minn. Dec., 1892.

Savage, Thomas Edmund, University of Illinois, Urbana, Ill. December, 19[illegible]

Schaller, Waldemar T., U. S. Geol. Survey, Washington, D. C. Dec., 1918.

Schofield, S. J., Geological Survey of Canada, Ottawa, Canada. Dec., 19[illegible]8

Schrader, Frank C., U. S. Geological Survey, Washington, D. C. Aug., 19[illegible]1.

Schuchert, Charles, Yale University, New Haven, Conn. August, 1895.

Schultz, Alfred R., Hudson, Wis. December, 1912.

Scott, William B., Princeton University, Princeton, N. J. August, 1892.

Seaman, Arthur E., Michigan College of Mines, Houghton, Mich. Dec., 1904.

Sellards, Elias H., University of Texas, Austin, Texas. December, 1905.

Shaler, Millard K., 66 Rue Des Colonus, Brussels, Belgium. Dec., 1914.

Shannon, Charles W., Oklahoma Geol. Survey, Norman, Okla. Dec., 1918.

Shattuck, George Burbank, Vassar College, Poughkeepsie, N. Y. Aug., 1899.

Shaw, Eugene W., U. S. Geological Survey, Washington, D. C. Dec., 1912.

Shedd, Solon, State College of Washington, Pullman, Wash. December, 1904.

Shepard, Edward M., 1403 Benton Ave., Springfield, Mo. August, 1901.

Shimek, Bohumil, University of Iowa, Iowa City, Iowa. December, 1904.

Shimer, Hervey Woodburn, Massachusetts Institute of Technology, Cambridge, Mass. December, 1910.

Shuler, E. W., South Methodist University, Dallas, Texas. December, 1920.

Siebenthal, Claude E., U. S. Geol. Survey, Washington, D. C. Dec., 1912.

*Simonds, Frederick W., University of Texas, Austin, Texas.

Sinclair, William John, Princeton University, Princeton, N. J. Dec., 1906.

Singewald, Joseph T., Johns Hopkins University, Baltimore, Md. Dec., 1911.

Sloan, Earle, Charleston, S. C. December, 1908.

Smith, Burnett, Syracuse University, Skaneateles, N. Y. December, 1911.

Smith, Carl, Box 1136, Tulsa, Okla. December, 1912.

*Smith, Eugene A., University of Alabama, University, Ala.

Smith, George Otis, U. S. Geological Survey, Washington, D. C. Aug., 1897.

Smith, Philip S., U. S. Geological Survey, Washington, D. C. Dec., 1909.

Smith, Warren Du Pré, University of Oregon, Eugene, Ore. December, 1909.

Smith, W. S. Tangier, 640 Tennyson Ave., Palo Alto, Calif. June, 1902.

*Smock, John C., Hudson, N. Y.

Smyth, Charles H., Jr., Princeton University, Princeton, N. J. Aug., 1892.

Smyth, Henry L., Harvard University, Cambridge, Mass. August, 1894.

Somers, R. E., Oil and Gas Bldg., University of Pittsburgh, Pittsburgh, Pa. December, 1919.

Soper, Edgar K., 120 Broadway, New York City, Room 3101. December, 1918.

Sosman, R. B., Geophysical Laboratory, Washington, D. C. December, 1920.

Speight, Robert, Christ Church, Canterbury College, New Zealand. Dec., 1916.

Spencer, Arthur Coe, U. S. Geological Survey, Washington, D. C. Dec., 1896.

*Spencer, J. W., 6 Earl St., Toronto, Canada.

Springer, Frank, U. S. National Museum, Washington, D. C. December, 1911.

Spurr, Josiah E., c/o Engineering and Mining Journal, 10th Ave. and 36th St., New York, N. Y. December, 1894.

Stanley-Brown, Joseph, 26 Exchange Place, New York, N. Y. August, 1892.

Stanton, Timothy W., U. S. National Museum, Washington, D. C. Aug., 1891.

Stauffer, Clinton R., Univ. of Minnesota, Minneapolis, Minn. Dec., 1911.

Stebinger, Eugene, Jr., U. S. Geological Survey, Washington, D. C. Dec., 1916

Steidtmann, Edward, University of Wisconsin, Madison, Wis. Dec., 1916.

STEPHENSON, LLOYD W., U. S. Geol. Survey, Washington, D. C. Dec., 1911.
*STEVENSON, JOHN J., 215 West 101st St., New York, N. Y.
STOLLER, JAMES HOUGH, Union College, Schenectady, N. Y. December, 1917
STONE, RALPH WALTER, U. S. Geological Survey, Washington, D. C. Dec., 1912.
STOSE, GEORGE WILLIS, U. S. Geological Survey, Washington, D. C. Dec., 1908
STOUT, WILBER, Geological Survey of Ohio, Columbus, Ohio. December, 1918
SWARTZ, CHARLES K., Johns Hopkins University, Baltimore, Md. Dec., 1908.
TABER, STEPHEN, University of South Carolina, Columbia, S. C. Dec., 1914.
TAFF, JOSEPH A., 781 Flood Building, San Francisco, Cal. August, 1895.
TALBOT, MIGNON, Mount Holyoke College, South Hadley, Mass. Dec., 1913
TALMAGE, JAMES E., 47 E. So. Temple St., Salt Lake City, Utah. Dec., 1897.
TARR, WILLIAM ARTHUR, University of Missouri, Columbia, Mo. Dec., 1917.
TAYLOR, FRANK B., Fort Wayne, Ind. December, 1895.
TILTON, J. L., Morgantown, W. Va. December, 1920.
*TODD, JAMES E., 905 Missouri Ave., Lawrence, Kans.
TOLMAN, CYRUS FISHER, JR., Leland Stanford, Jr., University, Stanford University, Calif. December, 1909.
TOMLINSON, CHARLES WELDON, 714 Ideal Bldg., Denver, Colo. December, 1917.
TROWBRIDGE, ARTHUR C., State Univ. of Iowa, Iowa City, Iowa. Dec., 1913.
*TURNER, HENRY W., Mills Building, San Francisco, Calif.
TWENHOFEL, WILLIAM H., University of Wisconsin, Madison, Wis. Dec., 1913.
TWITCHELL, MAYVILLE W., State Geological Survey, Trenton, N. J. Dec., 1911.
TYRRELL, JOSEPH B., Confederation Life Bldg., Toronto, Canada. May, 1889.
UDDEN, JOHAN A., University of Texas, Austin, Texas. August, 1897.
ULRICH, EDWARD O., U. S. Geological Survey, Washington, D. C. Dec., 1903.
UMPLEBY, JOSEPH B., University of Oklahoma, Norman, Okla. Dec., 1913.
*UPHAM, WARREN, Minnesota Historical Society, Saint Paul, Minn.
VAN HORN, F. R., Case School of Applied Science, Cleveland, Ohio. Dec., 1898.
VAN INGEN, GILBERT, Princeton University, Princeton, N. J. December, 1904.
VAN TUYL, FRANCIS M., Colorado School of Mines, Golden, Colo. Dec., 1917.
VAUGHAN, T. WAYLAND, U. S. Geol. Survey, Washington, D. C. August, 1896.
VEATCH, ARTHUR CLIFFORD, 7 Central Drive, Port Washington, N. Y. December, 1906.
*VOGDES, ANTHONY W., 2425 First St., San Diego, Calif.
WADE, BRUCE, State Geological Survey, Nashville, Tenn. December, 1920.
*WADSWORTH, M. EDWARD, School of Mines, Univ. of Pittsburgh, Pittsburgh, Pa.
*WALCOTT, CHARLES D., Smithsonian Institution, Washington, D. C.
WALKER, THOMAS L., University of Toronto, Toronto, Canada. Dec., 1903.
WARREN, CHARLES H., Massachusetts Institute of Technology, Boston, Mass. December, 1901.
WASHBURNE, C. W., 60 Liberty St., New York, N. Y. December, 1919.
WASHINGTON, HENRY STEPHENS, Geophysical Laboratory, Washington, D. C. August, 1896.
WATSON, THOMAS L., University of Virginia, Charlottesville, Va. June, 1900.
WEAVER, CHARLES E., 264 Herkimer Road, Utica, N. Y. December, 1913.
WEED, WALTER H., Tuckahoe, N. Y. May, 1889.
WEGEMANN, CARROLL H., 1129 Pennsylvania St., Denver, Colo. Dec., 1912.
WEIDMAN, SAMUEL, 814 Monett St., Norman, Okla. December, 1903.
WELLER, STUART, University of Chicago, Chicago, Ill. June, 1900.

WESTGATE, LEWIS G., 106 Morningside Drive, New York City. August, 1894.
WHERRY, EDGAR T., Bureau of Chemistry, Washington, D. C. Dec., 1915.
WHITE, DAVID, U. S. National Museum, Washington, D. C. May, 1889.
*WHITE, ISRAEL C., Morgantown, W. Va.
WHITLOCK, H. P., Amer. Museum of Natural History, N. Y. City. Dec., 1920.
WIELAND, GEORGE REBER, Yale University, New Haven, Conn. December, 1910.
WILDER, FRANK A., North Holston, Smyth County, Va. December, 1905.
*WILLIAMS, EDWARD H., JR., Woodstock, Vt.
WILLIAMS, IRA A., Oregon Bureau of Mines and Geology, 417 Oregon Bldg., Portland, Ore. December, 1905.
WILLIAMS, MERTON YARWOOD, Geological Survey, Ottawa, Canada. Dec., 1916.
WILLIS, BAILEY, Leland Stanford, Jr., University, Calif. December, 1889.
WILSON, ALFRED W. G., Department of Mines, Ottawa, Canada. June, 1902.
WILSON, MORLEY EVANS, Geological Survey, Ottawa, Canada. December, 1916.
WINCHELL, ALEXANDER N., University of Wisconsin, Madison, Wis. Aug., 1901.
*WINCHELL, HORACE VAUGHN, First National Society Bldg., Minneapolis, Minn.
*WINSLOW, ARTHUR, 131 State St., Boston, Mass.
WOLFF, JOHN E., Harvard University, Cambridge, Mass. December, 1889.
WOODMAN, JOSEPH E., New York University, New York, N. Y. Dec., 1905.
WOODWARD, ROBERT S., Carnegie Institution of Washington, Washington, D. C. May, 1889.
WOODWORTH, JAY B., Geological Museum, 38 Oxford St., Cambridge, Mass. December, 1895.
WRIGHT, CHARLES WILL, 28 Vie del Parliamento, Rome, Italy. Dec., 1909.
WRIGHT, FREDERIC E., Geophysical Laboratory, Carnegie Institution, Washington, D. C. December, 1903.
*WRIGHT, G. FREDERICK, Oberlin Theological Seminary, Oberlin, Ohio.
ZIEGLER, VICTOR, Colorado School of Mines, Golden, Colo. December, 1916.

CORRESPONDENTS DECEASED

CREDNER, HERMAN. Died July 22, 1913.
MICHEL-LÉVY, A. Died September, 1911.
ROSENBUSCH, H. Died January 20, 1914.
SUESS, EDWARD. Died April 20, 1914.
TSCHERNYSCHEW, TH. Died Jan. 15, 1914.
ZIRKEL, FERDINAND. Died June 11, 1912.

FELLOWS DECEASED

* Indicates Original Fellow (see article III of Constitution)

*ASHBURNER, CHAS. A. Died Dec. 24, 1889.
BARLOW, ALFRED E. Died May 28, 1914.
BARRELL, JOSEPH. Died May 4, 1919.
BELCHER, CHARLES E. Died Feb. 14, 1904.
*BECKER, GEORGE F. Died April 20, 1919.
BELL, ROBERT. Died June 18, 1917.
BICKMORE, ALBERT S. Died Aug. 12, 1914.
BLAKE, WM. PHIPPS. Died May 21, 1910.
BOWMAN, AMOS. Died June 18, 1894.
BROWN, AMOS P. Died Oct. 9, 1917.
BUCKLEY, ERNEST R. Died Jan. 19, 1912.
CAIRNES, D. D. Died June 14, 1917.
*CALVIN, SAMUEL. Died April 17, 1911.
CARPENTER, FRANK R. Died April 1, 1910.
*CHAPIN, J. H. Died March 14, 1892.
CLARK, WILLIAM B. Died July 27, 1917.
*CLAYPOLE, EDWARD W. Died Aug. 17, 1901.
*COMSTOCK, THEO. B. Died July 26, 1915.
COOK, GEORGE H. Died Sept. 22, 1889.
*COPE, EDWARD D. Died April 12, 1897.
CASTILLO, ANTONIO DEL. Died Oct.28,1895.
*DANA, JAMES D. Died April 14, 1895.
DAVIS, CHARLES A. Died April 9, 1916.
DAWSON, GEORGE M. Died March 2, 1901.
DAWSON, SIR J. WM. Died Nov. 19, 1899.
DERBY, ORVILLE A. Died Nov. 27, 1915.
DRYSDALE, CHAS. W. Died July 10, 1917.
DUTTON, CLARENCE E. Died Jan. 4, 1912.
*DWIGHT, WM. B. Died Aug. 29, 1906.
EASTMAN, CHAS. R. Died Sept. 27, 1918.
*ELDRIDGE, GEORGE H. Died June 29, 1905.
*EMMONS, SAMUEL F. Died March 28, 1911.
FONTAINE, WM. M. Died April 30, 1913.
*FOOTE, ALBERT E. Died October 10, 1895.
*FRAZER, PERSIFOR. Died April 7, 1909.
*FULLER, HOMER T. Died Aug. 14, 1908.
*GILBERT, GROVE K. Died May 1, 1918.
GIROUX, N. J. Died November 30, 1891.
HAGUE, ARNOLD. Died May 14, 1917.
*HALL, CHRISTOPHER W. Died May 10,1911.
*HALL, JAMES. Died August 7, 1898.
HATCHER, JOHN B. Died July 3, 1904.
*HAY, ROBERT. Died December 14, 1895.
HAYES, C. WILLARD. Died Feb. 9, 1916.
*HEILPRIN, ANGELO. Died July 17, 1907.
HILGARD, EUGENE W. Died Jan. 8, 1916.
HILL, FRANK A. Died July 13, 1915.
*HITCHCOCK, CHAS. H. Died Nov. 7, 1919.
*HOLMES, JOSEPH A. Died July 13, 1915.
HONEYMAN, DAVID. Died October 17, 1889.
*HOWELL, EDWIN E. Died April 16, 1911.
*HOVEY, HORACE C. Died July 27, 1914.
HUNT, THOMAS S. Died Feb. 12, 1892.
*HYATT, ALPHEUS. Died Jan. 15, 1902.
IDDINGS, J. P. Died Sept. 8, 1920.
IRVING, JOHN D. Died July 26, 1918.
JACKSON, THOMAS M. Died Feb. 3, 1912.
*JAMES, JOSEPH F. Died March 29, 1897.
JULIEN, ALEXIS A. Died May 7, 1919
KNIGHT, WILBUR C. Died July 28, 1903.
LACOE, RALPH D. Died February 5, 1901.
LAFLAMME, J. C. K. Died July 6, 1910.
LAMBE, L. M. Died March 12, 1919.
LANGTON, DANIEL W. Died June 21, 1909.
*LE CONTE, JOSEPH. Died July 6, 1901.
*LESLEY, J. PETER. Died June 2, 1903.
LOUGHRIDGE, ROBT. H. Died July 1, 1917.
McCALLEY, HENRY. Died Nov. 20, 1904.
*McGEE, W J. Died September 4, 1912.
MARCY, OLIVER. Died March 19, 1899.
MARSH, OTHNIEL C. Died March 18, 1899.
MELL, P. H. Died October 12, 1918.
*MERRILL, FRED. J. H. Died Nov. 29, 1916.
MILLS, JAMES E. Died July 25, 1901.
*NASON, HENRY B. Died January 17, 1895.
*NEFF, PETER. Died May 11, 1903.
*NEWBERRY, JOHN S. Died Dec. 7, 1892.
NILES, WILLIAM H. Died Sept. 12, 1910.
*ORTON, EDWARD. Died October 16, 1899.
*OSBORN, AMOS O. Died March, 1911.
*OWEN, RICHARD. Died March 24, 1890.
PENFIELD, SAMUEL L. Died Aug. 14, 1906.
PENHALLOW, DAVID P. Died Oct. 20, 1910.
PIRSSON, L. V. Died Dec. 8, 1919.
*PLATT, FRANKLIN. Died July 24, 1900.
PETTEE, WILLIAM H. Died May 26, 1904.
*POWELL, JOHN W. Died Sept. 23, 1902.
*PROSSER, CHAS. S. Died Sept. 11, 1916.
PURDUE, A. H. Died Dec. 12, 1917.
ROGERS, G. S. Died Nov. 18, 1919
*RUSSELL, ISRAEL C. Died May 1, 1906.
*SAFFORD, JAMES M. Died July 3, 1907.
*SCHAEFFER, CHARLES. Died Nov. 23, 1903.
SEELY, H. M. Died May 4, 1917.
SEÑA, J. C. DA COSTA. Died June 20, 1919.
*SHALER, NATHANIEL S. Died Apr. 10, 1906.
SUTTON, WILLIAM J. Died May 9, 1915.
TARR, RALPH S. Died March 21, 1912.
TIGHT, WILLIAM G. Died Jan. 15, 1910.
*VAN HISE, C. R. Died Nov. 19, 1918.

WACHSMUTH, CHAS. Died Feb. 7, 1896.
WESTON, THOMAS C. Died July 20, 1910.
WHITE, THEODORE G. Died July 7, 1901.
*WHITFIELD, ROBT. P. Died April 6, 1910.
*WILLIAMS, GEORGE H. Died July 12, 1894.
*WILLIAMS, J. FRANCIS. Died Nov. 9, 1891.
*WILLIAMS, H. S. Died July 31, 1918.
WILMOTT, ARTHUR B. Died May 8, 1914.
*WINCHELL, ALEX. Died Feb. 19, 1891.
*WINCHELL, NEWTON. Died May 1, 1914.
WRIGHT, ALBERT A. Died April 2, 1905.
YEATES, WILLIAM S. Died Feb. 19, 1908.

Summary

Correspondents	10
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Elected Fellows	420
Membership	465
Deceased Correspondents	6
Deceased Fellows	112

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 32, PP. 119-156 MARCH 31, 1921
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

PROCEEDINGS OF THE TWELFTH ANNUAL MEETING OF THE PALEONTOLOGICAL SOCIETY, HELD AT CHICAGO, ILLINOIS, DECEMBER 28-30, 1920.[1]

R. S. BASSLER, *Secretary*

CONTENTS

[1] Manuscript received by the Secretary of the Society March 3, 1921.

Session of Tuesday, December 28

The first general session of the Society scheduled for 2 p. m. Tuesday, December 28, was postponed until Wednesday morning, so that the members could meet with the Fellows of the Geological Society of America for the reading of the stratigraphic and paleontologic papers forming Group B of that Society's program..

Tuesday evening the members met at Rosenwald Hall with the Geological Society of America, the Mineralogical Society, and the Society of Economic Geologists, to hear the addresses of I. C. White, retiring President of the Geological Society, and of C. K. Leith, retiring Vice-President of Section E, American Association for the Advancement of Science, following which the four societies participated in a joint smoker.

Session of Wednesday, December 29

The twelfth annual meeting of the Society was called to order by President Loomis at 9.30 a. m., December 29, in Walker Museum of the University of Chicago. The report of the Council was presented by the Secretary as the first matter of business.

REPORT OF THE COUNCIL

To the Paleontological Society, in twelfth annual meeting assembled:

The meetings of the Council, as heretofore, have been limited to one following the last annual meeting and one immediately preceding the present session, all other business having been transacted by correspondence. The Council's administration of the Society's business for the twelfth year is presented in the following reports:

Secretary's Report

To the Council of the Paleontological Society:

The proceedings of the eleventh annual meeting of the Society, held at Boston, Massachusetts, December 30-31, 1919, are printed in volume 31, pages 197-232, of the Bulletin of the Geological Society of America.

The Council's proposed nominations for officers and the announcement that the twelfth annual meeting of the Society would be held at Chicago, December 28-30, 1920, as the guest of the University of Chicago, was issued March 15, 1920.

The nomination of Dr. Arthur Hollick as representative of the Paleontological Society on the Board of Control of Botanical Abstracts to succeed Dr. F. H. Knowlton, whose term had expired, was approved by the Council.

Membership.—During the year the Society has lost three members by death: Mr. Walter R. Billings, of Ottawa, Ontario, nephew of E. Billings and, like his distinguished relative, a student of the invertebrates of the Lower Paleozoic rocks of Canada; Mr. Homer Hamlin, of Los Angeles, California, and Mr. Wilbur L. Moody, of Berkeley, California, both students of Pacific Coast paleontology and stratigraphy.

One member has resigned during the year, the election of fourteen new members has just been concluded, and five additional nominations are awaiting consideration at the present meeting. This year four of our members have been elected to fellowship in the Geological Society of America. The result of these various changes leaves the total number of members at the end of 1920 as 209.

Publications.—Besides the Proceedings, eight papers published by the Society in the Bulletin of the Geological Society of America have been distributed to the members during the course of the year.

Pacific Coast Section.—The tenth annual meeting of the Pacific Coast Section of the Paleontological Society was held at Seattle, Washington, June 18, 1920, in conjunction with the Cordilleran Section of the Geological Society of America, the two societies participating in the fourth annual meeting of the Pacific Division of the American Association for

the Advancement of Science. The meeting was called to order by Dr. E. L. Packard, in the Science Hall of the University of Washington, and nine papers on the paleontology and stratigraphy of the west coast were presented. As an item of business, it was moved and carried that the new officers of the Pacific Coast Section should be voted on by mail at a later date determined by the secretary.

The election of officers was held in October, 1920, with the following results:

President, E. L. PACKARD.
Vice-President, B. L. CLARK.
Secretary, CHESTER STOCK.

The minutes of this section are printed on pages 145 to 149 of this Bulletin.

Respectfully submitted,

R. S. BASSLER,
Secretary.

WASHINGTON, D. C., *December* 27, 1920.

TREASURER'S REPORT

To the Council of the Paleontological Society:

The Treasurer begs to submit the following report of the finances of the Society for the fiscal year ending December 24, 1920:

RECEIPTS			
Cash on hand December 20, 1919		$623.76	
Membership fee		276.30	
Interest, Connecticut Savings Bank		23.58	
			$923.64
EXPENDITURES			
Treasurer's office:			
Treasurer's allowance	$25.00		
Printing and postage	16.50		
		$41.50	
Secretary's office:			
Secretary's allowance	$50.00		
Office expenses	68.52		
Clerical help	25.00		
		143.52	
Geological Society of America:			
For printing separates		54.94	
Pacific Coast Section:			
Assessment for the American Association for the Advancement of Science		15.00	
			254.96
Balance on hand December 24, 1920			$668.68

Net increase in funds		**$44.92**
Outstanding dues (1919), 2	**$6.00**	
Outstanding dues (1920), 3	**9.00**	
		$15.00

Respectfully submitted,

RICHARD S. LULL,
Treasurer.

NEW HAVEN, CONNECTICUT, *December* 24, 1920.

APPOINTMENT OF AUDITING COMMITTEE

Following the reading of the Treasurer's report, President Loomis appointed Messrs. Stuart Weller and A. W. Slocom as a committee to audit the accounts.

ELECTION OF OFFICERS AND MEMBERS

The result of the ballots for the election of officers for 1921 and of new members was then announced as follows:

OFFICERS FOR 1921

President:

T. W. STANTON, Washington, D. C.

First Vice-President:

C. K. SWARTZ, Baltimore, Maryland

Second Vice-President:

W. J. SINCLAIR, Princeton, New Jersey

Third Vice-President:

ARTHUR HOLLICK, New York City

Secretary:

R. S. BASSLER, Washington, D. C.

Treasurer:

RICHARD S. LULL, New Haven, Connecticut

Editor:

WALTER GRANGER, New York City

NEW MEMBERS FOR 1921

PERRY A. GLICK, 502 East Springfield Street, Champaign, Ill.
LEONARD WILSHIER HENRY, Morton Street, Portersville, Calif.
RAYMOND R. HIBBARD, 450 Carlton Street, Buffalo, N. Y.
HENRY V. HOWE, 1514 Alder Street, Eugene, Oregon.
DOROTHY B. KEMPER, 2527 Benevenue Street, Berkeley, Calif.
GEORGE FREDERICK MATTHEW, 115 Carmarthen Street, St. John, N. B.
FLORENCE EMMA MOSES, 5424 Claremont Avenue, Oakland, Calif.
ADOLF CARL NOÉ, University of Chicago, Chicago, Ill.
ESTHER E. RICHARDS, Rio Bravo Oil Company, Southern Pacific Building, Houston, Texas.
RICHARD JOEL RUSSELL, 2412 Piedmont Avenue, Berkeley, Calif.
ARTHUR WARE SLOCOM, Walker Museum, University of Chicago, Chicago, Ill.
FRANK PETER STRICKLAND, JR., 640 Oakland Street, Kansas City, Mo.
PARKER DAVIES TRASK, 1502 Alice Street, Oakland, Calif.
ALFRED OSWALD WOODFORD, Pomona College, Claremont, Calif.

AMENDMENT TO THE CONSTITUTION

The Secretary then announced the result of the balloting regarding the proposed amendment of Article III, section 5, of the Constitution, namely: "Fellows, Members, and Patrons are entitled to vote, but only Fellows are eligible to office in this Society," be amended so as to require only that the President of the Society be a Fellow. The amendment was lost, as less than one-half of the Fellows voted favorably, instead of the necessary three-fourths.

NEW NOMINATIONS AND ELECTION TO MEMBERSHIP

The President then directed the Secretary to read the list of new nominations, which had arrived too late for the printed ballot and which, having received the approval of the Council, were under consideration for election:

PAUL C. MILLER, Assistant Curator of Paleontology, Walker Museum, University of Chicago. Proposed by E. S. Riggs and F. B. Loomis.

RICHARD NEWMAN NELSON, graduate student, University of California. B. A. University of Oregon (1919). Proposed by Chester Stock and B. L. Clark.

NORMAN E. NELSON, 116 East Eighth Street, Fort Worth, Texas. Student of Cretaceous paleontology and stratigraphy. Proposed by E. O. Ulrich and R. S. Bassler.

WILL McCLAIN WINTON, Professor of Biology and Geology, Texas Christian University, Forth Worth, Texas. M. S., Vanderbilt University (1908). Proposed by E. O. Ulrich and R. S. Bassler.

OTTO T. WALTER, Research assistant in paleontology, University of Iowa. M. S., University of Iowa (1917). Proposed by A. O. Thomas and R. S. Bassler.

Upon motion by Professor Weller, it was voted that the By-Laws be suspended and that the Secretary cast the vote of the Society for the election to membership of these five new nominees.

ELECTION OF CORRESPONDENT

President Loomis then reported that the Council favored the election as Correspondent of Monsieur Ferdinand Canu, 18 Rue du Peintre Lebrun, Versailles, France, in view of his researches on paleogeography and his various monographs and essays on the fossil bryozoa of both Europe and America, his work on the latter culminating in the two quarto volumes forming Bulletin 106, U. S. National Museum, entitled "North American Early Tertiary Bryozoa." Monsieur Canu's election followed by unanimous vote.

With the completion of the business meeting, the Society proceeded, in general session, with President Loomis in the chair, to the reading of papers.

PRESENTATION OF PAPERS

The first paper of the session, presented by the author and illustrated by lantern slides, gave the results of ten years of exhibition work in paleontology at the New National Museum; discussion by Messrs. Moore and Weller.

PALEONTOLOGICAL EXHIBITS AT THE U. S. NATIONAL MUSEUM

BY R. S. BASSLER

(Abstract)

As this meeting marks the end of the first decade of exhibition in the New National Museum, a report of progress seemed appropriate. The general difficulty of preparing interesting exhibits of fossil remains is increased in the National Museum by the fact that the interest must be national and not local. The methods of obtaining this result will be explained by lantern slides illustrating the three main halls of paleontology and by samples of the descriptive labels employed. Each hall is devoted to a special branch of paleontology, namely, the vertebrate, invertebrate, and plant divisions, and the exhibits in each are arranged for study by the biologist, geologist, and the general public. For the first, there is a biological series, in which the evolution of the various classes of organisms is the essential theme; for the geologist, the characteristic fossils and rocks of each formation are arranged chronologically and accompanied by a long structure section across the continent: for the general public, large exhibits illustrating subjects which include matters of geological history, in addition to the display of fossils and their occurrence in the rocks, are displayed, usually on bases open to inspection by the visitor. In this latter series a fossil coral reef, a large block showing an unconformity, sea beaches of various geological periods, and similar subjects are included.

An instructive paper on Paleozoic cephalopods, illustrated by diagrams and read, in the absence of the author, by President Loomis, brought forth a discussion by Messrs. Foerste, Chadwick, and Bassler.

OBSERVATIONS ON THE MODE OF LIFE OF PRIMITIVE CEPHALOPODS

BY R. RUEDEMANN

(*Abstract*)

The purpose of this paper is to record some new observations on the life habits of the earlier cephalopods based on specimens of *Orthoceras* from the Trenton limestone and Guelph dolomite of New York, retaining color lines on one side, and others from the Utica and Lorraine shales of New York, showing sexual differences in size, shape, and surface sculpture.

The Secretary then presented for the author, in his absence, an account of the wonderful anatomical structures preserved in the Middle Cambrian Burgess shale branchiopod crustacea found near Field, British Columbia. Illustrated by lantern slides and specimens.

ANATOMY OF MIDDLE CAMBRIAN CRUSTACEA

BY CHARLES D. WALCOTT

(*Abstract*)

A presentation of the appendages and internal anatomy of the three Middle Cambrian branchiopod genera, *Waptia*, *Naroia*, and *Burgessia*, preliminary to a more detailed work to be issued in the near future by the Smithsonian Institution.

The following papers were read by title:

AMERICAN SPECIES OF THE GENUS SCHWAGERINA AND THEIR STRATIGRAPHIC SIGNIFICANCE

BY J. W. BEEDE

GRAPTOLITE LOCALITIES OF WESTERN NORTH AMERICA, WITH DESCRIPTION OF TWO NEW FORMATION NAMES

BY L. D. BURLING

(*Abstract*)

The greater part of the paper is taken up with summaries and correlations of the available published information with reference to the twelve known graptolite localities in western North America.

Three new graptolite localities are described for western North America, all in the Desert ranges of Utah, and reported on by Ulrich, whose reports are copied.

Additional stratigraphic data are presented regarding two of the twelve known localities: Glenogle (British Columbia) and the Yukon-Alaska boundary. Regarding the former (Glenogle) this paper corrects the accepted reference of the Glenogle graptolites to "Kicking Horse Pass." It regards and discusses the discovery of fossils below, and makes a correction in the stratigraphy of the beds above, the graptolite shales, for which it proposes the formational name Glenogle shales. The beds above are shown to be of Richmond age, the first recorded instance of Richmond beds west of Lake Winnipeg and north of the Canadian boundary. Regarding the latter (Yukon-Alaska boundary) this paper lists four new localities in the general vicinity of the one previously known and presents new light on the stratigraphy of the graptolite-bearing beds, giving a section of the Paleozoic beds south of the Tatonduk River and defining one new formation, the Tatonduk shales. These collections have all been reported on by Doctor Ruedemann, whose reports are copied. There is also recorded a slight change in the recorded localities for *Dicranograptus nicholsoni whitianus* (Miller).

The bearing of the data presented on such questions as the number of graptolite horizons in the West, their origin and dispersal, is discussed and the conclusions drawn that there appear to be several horizons, and that the main channels of communication probably opened to the north.

The next paper was read by title.

NEW KIND OF TYPE SPECIMEN

BY E. L. TROXELL

The next paper, illustrated by lantern slides and dealing with several Upper Cambrian trilobites of Iowa, was presented by the author and discussed by Messrs. Weller and Chadwick.

UPPER CAMBRIAN TRILOBITES

BY O. T. WALTER

(Abstract)

As far as now known, only three trilobites have been reported from the Upper Cambrian of Iowa, namely, *Dikelocephalus minnesotensis* Owen, *Illænurus quadratus* Hall, and a new species of *Illænurus*, here designated as *Illænurus calvini*. These three species are found associated in the Saint Lawrence limestone near Lansing, Allamakee County, Iowa. *Illænurus quadratus* Hall occurs somewhat doubtfully at this place, while *Illænurus calvini* is found in abundance and in association with *Dikelocephalus minnesotensis*. As in the case with the latter, the new *Illænurus* is more or less dismembered; a restoration brings out several interesting features. The first reference made to *I. calvini* was by the late Prof. S. Calvin in the Iowa Geological Survey, volume IV, page 58. This species differs notably from *I. quadratus* in the presence of long postero-lateral extensions of the fixed cheeks.

Some notes on a trilobite from the province of Szechuan, west China, are also presented.

A stratigraphic paper giving a detailed classification and description of the Niagaran rocks of northern Michigan was then read by the author and brought forth discussion from Messrs. Twenhofel, Foerste, and M. Y. Williams.

NIAGARAN ROCKS OF THE NORTHERN PENINSULA OF MICHIGAN

BY G. M. EHLERS [1]

(Abstract)

The Niagaran rocks of the northern peninsula of Michigan, with the exception of those exposed in the Limestone Mountain outlier in Houghton County, are at or near the surface of a wide belt of land bordering the northern shores of Lakes Huron and Michigan. These rocks consist almost entirely of limestones and dolomites, are remarkable for their continuity from Wisconsin to Ontario, and have a maximum thickness of nearly 1,000 feet.

A classification of these rocks is proposed in which the strata, beginning at the base, are grouped under the names Mayville, Burnt Bluff, Manistique, and Racine formations.

The Mayville formation is a northeastward continuation of the Mayville beds of Wisconsin. The base of the formation in Michigan has not been seen; the top is provisionally placed at the top of a yellowish gray dolomite containing numerous remains of the brachiopod named *Virgiana mayvillensis* by Savage. This horizon extends eastward as far as Manitoulin and Fitzwilliam Islands, Ontario, in which regions it is included in the upper part of the Cataract formation by M. Y. Williams. It is thought that this horizon is younger than Cataract, and that the entire Mayville formation is of Niagaran age instead of Alexandrian, as stated by Savage. The *Virgiana mayvillensis* dolomite of the Mayville probably represents the same stratigraphic horizon as the *Virgiana (Conchidium) decussata* beds of Limestone Mountain, Michigan, of the Hudson Bay region, and of the Stonewall limestone of Manitoba.

The overlying Burnt Bluff formation seems to be limited above by a disconformity, and with little doubt is a northeastward extension of the Byron, Transition, and lower part of the Lower Coral Beds of Wisconsin. Certain beds of the formation—that is, the Fiborn limestone and upper part of the Hendricks series of R. A. Smith's tentative classification—are regarded by Savage and Crooks as being of Alexandrian age. The Burnt Bluff formation, which includes these beds, is thought by the writer to be of Niagaran age. The formation without doubt is equivalent to the Severn River limestone of the Hudson Bay region and the Wabi formation of the Lake Timiskaming region.

The Manistique formation is a northeastward extension of the Upper Coral Beds and the upper part of the Lower Coral Beds of Wisconsin. The well known coral horizon of this formation, which also occurs in the Upper Coral Beds of Wisconsin, is represented by the Fossil Hill coral horizon of the Lockport formation of Manitoulin Island and by a similar horizon in the Lockport of the Lake Timiskaming region.

[1] Introduced by E. C. Case.

The Racine formation of Michigan is an extension of the formation in Wisconsin which James Hall designated as the Racine limestone. The formations in Ontario, which are thought to be included in the Racine, are the Guelph and the thick-bedded, white to very light gray dolomite at the top of the Lockport of Cockburn and Manitoulin islands.

Following Mr. Ehler's paper was an account by Dr. Roy L. Moodie of his recent researches in paleopathology. This paper, which was illustrated by lantern slides, was supplemented by a demonstration later of specimens and microscopic preparations in an adjoining laboratory to those interested.

STATUS OF OUR KNOWLEDGE OF MESOZOIC PATHOLOGY

BY ROY L. MOODIE

(*Abstract*)

This paper discusses the degree of progress disease made during the Mesozoic. Fifteen pathological results, classified under the following five headings, will be described: 1, Arthritides; 2. Tumors; 3, Necroses; 4, Hyperostoses; 5, Fractures.

An account of the small fossils obtained by washing the Devonian shales of Iowa followed, and was presented by the author, with illustrations by lantern slides.

SMALL FOSSILS FROM THE LIME CREEK SHALES

BY A. O. THOMAS

(*Abstract*)

At the last meeting of the Paleontological Society the writer reported the finding of dissociated plates, spines, and parts of the lantern of three Devonian sea-urchins from the Lime Creek shales of Iowa. Since then quantities of the marly shales in which these occur have been screened and then washed through a series of fine-meshed sieves with the purpose of trying to find ambulacral plates and other small parts of the dissociated tests. In this manner many of the small parts of the echinoids were secured and, in addition, some ostracod valves and a few foraminifera. This led to more screening and washing from several horizons with excellent results. Bolting cloth was used to catch some of the very finest material. The small forms were then sorted out of the dried screenings under a Zeiss binocular.

In the coarser siftings examined occur a few of the larger forms mentioned below; also some juvenile brachiopods, fragments of shells and bryozoa, bits of coral, pieces of spines, and plates of sea-urchins, and various other broken organic remains.

The finer siftings, however, yield the best results. At several horizons the commonest fossils are the spirally marked, spheroidal bodies of doubtful affini-

ties, known as *Calcisphæra robusta* Williamson. They occur by the score, and lumps of the shale may be found in which large numbers of them are massed together. A few have been isolated on which the spiral lines are double.

Among the foraminifera a rotaline form is fairly common. It seems to belong to a new genus. *Lagena* and *Saccamina* are rare; the latter gives evidence of occurring in chains, as illustrated by Brady and others. A *Globigerina*-like species is found sparingly at one or two horizons. Minute tetractinellid spicules represent the sponges.

Conodont teeth referable to the genus *Polygnathus* occur. These microscopic translucent worm remains are beautifully preserved and are among the smallest forms recovered. Small, slender, annulated shells of *Tentaculites* are common in nearly every pan of the marl. Their exquisite hyaline tips are preserved in many cases. Some of these are doubtless the young of a new species of *Tentaculites* from the same beds and which reach a length of five millimeters or more.

The screenings are rich also in shells of tiny ostracods. Some of the genera are abundant and are represented by more than one species; a few, notably *Entomis*, are very rare. The commonest genera are *Bairdia*, *Kirkbyina*, *Bythocypris*, *Cypridina*, and *Beyrichia*, while there are several forms which have not been generically determined.

The meeting then adjourned for luncheon.

PRESIDENTIAL ADDRESS

At 2 p. m. the Society met to hear the address of the retiring President of the Paleontological Society, entitled

ORIGIN OF THE SOUTH AMERICAN FAUNAS

PRESIDENTIAL ADDRESS BY F. B. LOOMIS

Following this address, the reading of the papers prepared for the symposium and arranged for the meeting was taken up.

SYMPOSIUM ON CRITERIA AND METHODS EMPLOYED IN PALEONTOLOGIC RESEARCH

CRITERIA FOR THE DETERMINATION OF THE CLIMATIC ENVIRONMENT OF EXTINCT ANIMALS

BY E. C. CASE

CRITERIA FOR DETERMINATION OF CLIMATE BY MEANS OF FOSSIL PLANTS

BY F. H. KNOWLTON

METHODS OF DETERMINING THE RELATIONSHIPS OF MARINE INVERTEBRATE FOSSIL FAUNAS

BY CHARLES SCHUCHERT

CRITERIA FOR SPECIES, PHYLOGENIES, AND FAUNAS OF TRILOBITES

BY P. E. RAYMOND

AGE DETERMINATION OF FAUNAS

BY E. O. ULRICH

METHODS OF CREATING POPULAR INTEREST IN EXHIBITS OF FOSSILS

BY E. S. RIGGS

Upon the completion of the symposium, the reading of papers on the regular program was resumed.

PRESENTATION OF PAPERS

In the absence of the author, the following was read by the Secretary:

DECREASING SALINITY OF THE PLEISTOCENE CHAMPLAIN SEA GOING SOUTHWARD, AS SHOWN BY THE CHARACTER OF THE FAUNA, WITH A BRIEF DISCUSSION OF THE PLEISTOCENE FAUNA OF THE HUDSON VALLEY AND ITS SIGNIFICANCE [1]

BY WINIFRED GOLDRING

(*Abstract*)

Recent collecting in the Pleistocene deposits of the Champlain and Saint Lawrence valleys has called attention to the fact that going southward there is a marked change in the fauna, similar to that seen in the Baltic Sea today. Careful study of this fauna and comparison with the conditions found in the Baltic and elsewhere has led to the conclusion that the character of the Champlain fauna is due in large part at least to decreasing salinity southward in the waters of that time.

The Baltic Sea shows a very striking decrease in salinity eastward and, in a large way, the responses of the fauna to it. As the salinity of the water decreases from that normal for sea-water, the fauna changes from one typically marine to one in which only a few marine groups are represented and finally to a fresh-water fauna. Another striking change has been noted in the character of the Baltic fauna which may likewise be correlated with the variation in salinity: As the stenohaline forms disappear entirely, euryhaline forms become dwarfed. Modifications due to changes in the salt content of water are not confined to invertebrates alone. The dwarfing of fishes in the Baltic has been noted above; also the fishes of the Black Sea in their paucity of specific forms (compared with those of the Mediterranean) and marvelously great number of individuals are very indicative of the estuarine character of its waters.

A careful list, with localities, has been compiled of the Pleistocene invertebrate species collected by the writer and also all those reported by others in various publications, and these have been tabulated to show the distribution of the species from the sea (Labrador) to the southernmost locality (two miles

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[1] This paper will appear in full in a New York State Museum Bulletin.

south of Crown Point station) from which they have been collected in the Champlain area.

Comparisons have been made of specimens of the Pleistocene species of the Champlain area with those of Canada and with recent representatives, and it has been found that the Champlain fauna is a dwarf fauna.

The Pleistocene fauna of the Hudson Valley is briefly considered. No fossils have been reported from these Pleistocene deposits south of Croton Point, either from the New York or New Jersey shores. The most northern point at which Pleistocene fossils have been reported from the Hudson Valley is at Storm King, 50 miles above New York, where was found, in drilling a series of holes across the Hudson bed, a fauna represented by two species living at present along the New England and New Jersey coasts, *Mulinia lateralis* and *Trivia trivittata*. This has been shown by Shimer to be a dwarf fauna. At Croton Point, about 20 miles farther south, occurs a large Pleistocene oyster bed in which are found the following marine forms: *Mya arenaria*, *Modiola demissus*, *Mulinia lateralis*, and *Alectrion* (= *Nassa*) *obsoleta*. The largest specimen of *Mulinia lateralis* here is larger than the large specimens from Storm King, but smaller than the recent shore forms, as one might expect in waters of decreasing salinity. Salt-water organisms at present pass up the Hudson only to the Highlands, though its waters are brackish as far north as Poughkeepsie.

The data for the Hudson Valley Pleistocene fauna are meager, but the evidence obtained, however, seems to lead to conclusions similar to those arrived at for the Champlain area. The waters of the Pleistocene Hudson estuary were so freshened going northward that (1) only a few marine forms were able to advance into these waters at all; (2) so far as present knowledge goes, only two species reached as far up as Storm King, 50 miles above New York, and none have been reported north of this locality; (3) the two species found at Storm King represent a dwarf fauna, one of them, *Mulinia lateralis*, occurring in a dwarfed condition (less so, however) at Croton Point, about 20 miles farther south.

It is recognized that clay deposited in fresh water shows a laminated character not found in similar deposits in very brackish or salt water. The laminated character of the Hudson Valley clays, seen as far south as Haverstraw, and the absence of this peculiar laminated character in any of the localities in the Champlain area where marine fossils were found verifies what has already been indicated by the distribution and character of the faunas of these areas: (1) that the Pleistocene waters of the Hudson Valley were fresh or practically fresh north of Storm King; (2) that the Champlain Sea extended southward in a brackish condition, gradually freshened to a point a few miles south of Crown Point station, and that south of this area its waters were fresh or practically fresh.

At 5.30 the Society adjourned until the following day.

Wednesday evening at 7 o'clock the members attended the annual dinner of the Geological Society of America and affiliated societies, at the Chicago Beach Hotel.

Session of Thursday, December 30

Thursday morning at 9.30 the Society met in general session, with President Loomis presiding.

REPORT OF THE AUDITING COMMITTEE

The report of the Auditing Committee was announced, attesting to the correctness of the Treasurer's accounts; whereupon it was voted by the Society that the report be accepted.

PRESENTATION OF PAPERS

The first paper on the program was an account of some interesting plant remains, illustrated by lantern slides and presented by the author.

CYCADLIKE LEAVES FROM THE PERMIAN OF TEXAS

BY ADOLF C. NOÉ

(*Abstract*)

Among a number of fossil plants collected in 1920 in Baylor County, Texas, by Mr. Paul Miller, Assistant Curator of Walker Museum, University of Chicago, are a number of cycadlike leaves. The purpose of this paper is to describe and illustrate these leaves, which had been found in a bed of Permian shale, and to compare them with similar leaves which Prof. G. R. Wieland has described from the Lias of Mexico and with other early cycadeoid impressions. Their main interest lies in the fact that they are among the earliest known representatives of Cycadophytes. Since no seeds were discovered in connection with these leaves, it is impossible to determine whether they belong to true Cycads, or Williamsonias, or Cycadofilicales, but the fronds strongly resemble those of true Cycads.

The three following papers on paleobotany were then read by title:

GENUS SEQUOIA IN THE MESOZOIC

BY E. C. JEFFREY

(*Abstract*)

The author has had the opportunity of examining for the first time large quantities of twigs, with structure preserved, belonging to the genus *Sequoia* as recognized in the American Cretaceous. It is clear, from the evidence here furnished, that the organization of these twigs has little in common with that of our living Sequoias and their allies. They in fact are the branches of Araucarian conifers—a possibility long ago suggested by Saporta on the basis of their external habit. A recent suggestion that these twigs are wrongly identified has been withdrawn by its author, who now maintains that the

anatomical evidence does not prove their Araucarian affinities. Work carried out under the author's supervision makes it clear that true remains of the genus *Sequoia* do not make their appearance till the upper members of the Laramie series are reached. It will be necessary in the future to distinguish between the true Sequoias of the later Laramie and of the Tertiary and those Araucarian forms masquerading as Sequoias in the earlier Cretaceous and the Jurassic.

GENUS ARAUCARIOXYLON IN THE AMERICAN CRETACEOUS

BY E. C. JEFFREY

(*Abstract*)

The author and his students have collected material of *Araucarioxylon* from numerous localities and geological horizons of the North American Cretaceous, which supply reasons for modifications in our views as to the origin of the genus. It is generally assumed that the genus *Araucarioxylon* definitely connects the Araucarian conifers of the present epoch with the Cordiatales of the Paleozoic. The structure of woods in the American Cretaceous lends little support to that opinion, since they are less like the wood of *Cordaites* than are the woods of *Araucaria* and *Agathis*. The woods of the Araucarioxylon type in our deposits have the organization of Cupressinoxyla and the earlier annual rings of stems lack the Araucarioxylon-pitting. It is assumed from these data that the living Araucarian conifers are not closely related to the Cordaitales, but rather to a complex from which the Abietineæ or Pine family has taken origin. The roots of the living genera of the Araucarineæ are organized largely as is the stem of their Cretaceous ancestors.

CUPRESSINOXYLA OF THE MESOZOIC

BY E. C. JEFFREY

(*Abstract*)

The genus *Cupressinoxylon*, established many years ago, is of wide occurrence in the Jurassic and Cretaceous. It is generally assumed that woods of this type are to be referred to the Cupressineæ, Taxodineæ, or Podocarpineæ. The intention of the present communication is to show that many such woods are of Araucarian affinities. In a number of instances Araucarian pitting can be observed in such woods, while in others more refined criteria of Araucarian affinities have to be employed. Evidence is supplied on the one hand of the character of the ancestors of these Araucarian Cupressinoxyla and proof is furnished on the other of their being the ancestral types from which the living Araucariineæ have been derived. The genus *Cupressinoxylon* is formed as a response to marked seasonal variations of temperature and evidence is furnished for this conclusion.

An instructive presentation, illustrated by lantern slides and specimens, of a new reptilian suborder followed:

DESMATOSUCHUS SUPRENSIS FROM THE DOCKUM TRIASSIC BEDS OF WESTERN TEXAS

BY E. C. CASE

(*Abstract*)

Desmatosuchus represents a new suborder of phytosauroid reptiles. The skull is characterized by the presence of a single temporal opening, the lack of a parietal foramen, a large antorbital opening, lateral nares, and a much reduced quadrate.[1] The vertebral column is essentially phytosaurian in character; very little of the limb bones or girdles was found. The back was covered by an armor, consisting of four rows of plates, which extended from the skull to the extremity of the tail. The outer row of plates carried sharp spines, which were larger in the cervical region. The fifth pair of outer plates carried enormously developed spines, nearly eighteen inches in length, which curved outward and forward.

The condition of the skull permitted a plastic cast to be made of the endocranial region. This shows the brain to have been relatively very small compared to the size of the animal. There was hardly any expansion of the cerebral lobes; the hypophysis is very large, and there is a smaller epiphysis or paraphysis with lateral processes. The position and size of the optic region and the location of the various cranial nerves are clearly shown on the cast.

In the absence of their authors, four papers dealing with fossil vertebrates were then read by title:

EVOLUTION, PHYLOGENY, AND CLASSIFICATION OF THE PROBOSCIDEA

BY HENRY FAIRFIELD OSBORN

CLASSIFICATION OF THE REPTILES

BY W. K. GREGORY

JURASSIC FISHES COLLECTED BY BARNUM BROWN IN CUBA

BY W. K. GREGORY

RELATIONSHIP OF THE GREAT BASIN AND GREAT PLAINS FAUNAS

BY E. L. TROXELL

An outline of paleobotanic work in progress on the Tertiary rocks of the West was presented by the author under the title

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[1] A preliminary description of the skull and armor appeared in the Journal of Geology, vol. xxviii, no. 6, 1920.

PRELIMINARY NOTES ON RECENT TERTIARY COLLECTIONS IN THE WEST

BY RALPH W. CHANEY

(*Abstract*)

Collections of fossil plants were made during the past summer under the auspices of the University of California. In the John Day Basin material was secured from three horizons, in which some new species are represented; several new localities were discovered, including one at the type locality of the Mascall formation, where the flora resembles that previously secured from the Mascall, but contains a number of forms which indicate a swamp habitat. A collection from The Dalles group is of particular interest, since few fossils have been previously secured from this formation. The modern aspect of the leaves of this flora suggests its Pliocene or Pleistocene age. In the Sierras the Auriferous Gravels were visited, and limited collections made; these will be supplemented by collections during the coming field season, which will, it is hoped, establish the age or ages of the various gravel deposits.

The final paper on the program was given by President Loomis, who presented a discussion of the Lower Harrison Oreodonts, and especially the criteria for the determination of species and genera, under the title

LOWER HARRISON OREODONTS

BY F. B. LOOMIS

At 11.30 a. m. the Society adjourned.

Under the leadership of E. S. Riggs, the members then had the pleasure of a visit to the Field Museum, where several hours were spent in viewing the new building and in studying the exhibition collections and their installation.

Register of the Chicago Meeting, 1920

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Anderson, Robert, 47 Parliament St., Westminster, S. W. I., London, England.
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Brown, Thomas C., Laurel Bank Farm, Fitchburg, Mass.
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Doneghy, John T., 5618 Clemens Avenue, St. Louis, Mo.
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Dunbar, Carl O., Department of Geology, Yale University, New Haven, Conn.
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MARK, CLARA G., Department of Geology, Ohio State University, Columbus, Ohio.
MARTIN, BRUCE, Waukena, Tulare County, Calif.
MATHER, K. F., Denison University, Granville, Ohio.
MATTHEW, W. D., American Museum of Natural History, New York City.
MAYNARD, T. POOLE, 1622 D. Hunt Building, Atlanta, Ga.
McEWAN, EULA D., Simpson College, Indianola, Iowa.
MEHL, MAURICE G., University of Missouri, Columbia, Mo.
MERRIAM, JOHN C., Carnegie Institution, Washington, D. C.
MESLER, RECTOR D., U. S. Geological Survey, Washington, D. C.
MOODIE, ROY L., University of Illinois, Congress and Honore Sts., Chicago, Ill.
MOODY, CLARENCE L., University of California, Berkeley, Calif.
MOOK, CHARLES C., American Museum of Natural History, New York City.
MOORE, R. C., Department of Geology, University of Kansas, Lawrence, Kans.
MORAN, ROBERT B., 408 S. Spring Street, Los Angeles, Calif.
MORSE, WILLIAM C., Department of Geology, Mississippi Agricultural and Mechanical College, Agricultural College, Miss.
NARRAWAY, JAMES E., Department of Justice, Ottawa, Canada.
NOMLAND, JORGEN O., 200 Bush Street, San Francisco, Calif.
O'CONNELL, MARJORIE, American Museum of Natural History, New York City.
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OSBORN, HENRY FAIRFIELD, American Museum of Natural History, N. Y. City.
PACK, R. W., U. S. Geological Survey, Washington, D. C.
PACKARD, EARL L., Mississippi Agricultural and Mechanical College, Agricultural College, Miss.
PARKS, WILLIAM A., University of Toronto, Toronto, Ontario.
PATTEN, WILLIAM, Dartmouth College, Hanover, N. H.
PETERSON, O. A., Carnegie Museum, Pittsburgh, Pa.
PETRUNKEVITCH, ALEXANDER, 266 Livingston Street, New Haven, Conn.
PRICE, WILLIAM A., JR., Compania Transcontinental de Petroleo S. A., Apartado 657, Tampico, Mexico.
RAYMOND, PERCY E., Museum of Comparative Zoology, Cambridge, Mass.
REEDS, CHESTER A., American Museum of Natural History, New York City.
REESIDE, JOHN B., JR., U. S. Geological Survey, Washington, D. C.
RESSER, CHARLES E., U. S. National Museum, Washington, D. C.
RIGGS, E. S., Field Museum of Natural History, Chicago, Ill.
ROBINSON, WILBUR I., Geological Survey of Michigan, Lansing, Mich.
ROUNDY, PAUL V., U. S. Geological Survey, Washington, D. C.
ROWLEY, ROBERT R., Louisiana, Mo.
RUEDEMANN, RUDOLF, Education Building, Albany, N. Y.
SARDESON, FREDERICK W., 414 Harvard Street, Minneapolis, Minn.
SARLE, CLIFTON J., University of Arizona, Tucson, Ariz.
SAVAGE, THOMAS E., University of Illinois, Urbana, Ill.
SHIDELER, WILLIAM H., Miami University, Oxford, Ohio.
SCHUCHERT, CHARLES, Yale University, New Haven, Conn.

SCOTT, WILLIAM B., Princeton University, Princeton, N. J.
SELLARDS, ELIAS H., University of Texas, Austin, Texas.
SHIMER, HERVEY W., Massachusetts Institute of Technology, Boston, Mass.
SINCLAIR, WILLIAM J., Princeton University, Princeton, N. J.
SMITH, BURNETT, Syracuse University, Syracuse, N. Y.
SPRINGER, FRANK, U. S. National Museum, Washington, D. C.
STANTON, T. W., U. S. Geological Survey, Washington, D. C.
STAUFFER, CLINTON R., University of Minnesota, Minneapolis, Minn.
STEPHENSON, L. W., U. S. Geological Survey, Washington, D. C.
STERNBERG, CHARLES H., Balboa Park, San Diego, Calif.
STOCK, CHESTER, 492 Seventh Street, San Francisco, Calif.
STOVER, REGINALD C., Standard Oil Building, San Francisco, Calif.
SWARTZ, CHARLES K., Johns Hopkins University, Baltimore, Md.
TALBOT, MIGNON, Mt. Holyoke College, South Hadley, Mass.
TELLER, EDGAR E., 305 Ellicott Street, Buffalo, N. Y.
THOMAS, A. O., Department of Geology, University of Iowa, Iowa City, Iowa.
THOMPSON, ALBERT, American Museum of Natural History, New York City.
THORPE, MALCOLM R., Peabody Museum, New Haven, Conn.
TROXELL, EDWARD L., Osborn Botanical Laboratory, New Haven, Conn.
TWENHOFEL, WILLIAM H., University of Wisconsin, Madison, Wis.
TWITCHELL, M. W., Geological Survey of New Jersey, Trenton, N. J.
ULRICH, EDWARD O., U. S. Geological Survey, Washington, D. C.
UNGER, CLAUDE E., Pottsville, Pa.
VAN DELOO, JACOB, Education Building, Albany, N. Y.
VAN INGEN, GILBERT, Princeton University, Princeton, N. J.
VAN TUYL, FRANCIS M., Colorado School of Mines, Golden, Colo.
VAN WINKLE, KATHERINE E. H., 126 Kelvin Place, Ithaca, N. Y.
VAUGHAN, T. WAYLAND, U. S. Geological Survey, Washington, D. C.
VOGDES, ANTHONY W., 2425 First Street, San Diego, Calif.
WAGNER, CARROLL MARSHALL, 2520 Wilshire Building, Los Angeles, Calif.
WALCOTT, CHARLES D., Smithsonian Institution, Washington, D. C.
WEAVER, CHARLES F., Deerfield, Oneida County, N. Y.
WELLER, STUART, University of Chicago, Chicago, Ill.
WHITE, DAVID, U. S. Geological Survey, Washington, D. C.
WHITTAKER, EDWARD J., Geological Survey of Canada, Ottawa, Canada.
WIELAND, G. R., Yale University, New Haven, Conn.
WILLIAMS, MERTON Y., Geological Survey of Canada, Ottawa, Canada.
WILSON, ALICE E., Victoria Memorial Museum, Ottawa, Canada.
WILSON, HERRICK E., 224 West College Street, Oberlin, Ohio.
WOODRING, WENDELL P., U. S. Geological Survey, Washington, D. C.

CORRESPONDENT DECEASED

KOKEN, E., died November 24, 1912.

MEMBERS DECEASED

BARRELL, JOSEPH, died May 4, 1919.
BILLINGS, WALTER R., died March 1, 1920.
CALVIN, SAMUEL, died April 17, 1911.
CLARK, WILLIAM B., died July 27, 1917.

DERBY, ORVILLE A., died November 27, 1915.
EASTMAN, CHARLES R., died September 27, 1918.
FONTAINE, WILLIAM M., died April 30, 1913.
GILL, THEODORE N., died September 25, 1914.
GORDON, ROBERT H., died May 10, 1910.
HAMLIN, HOMER, died in July, 1920.
HARPER, GEORGE W., died August 19, 1918.
HAWVER, J. C., died May 15, 1914.
LAMBE, LAWRENCE M., died March 12, 1919.
LYON, VICTOR W., died August 17, 1919.
MOODY, W. L., died October 9, 1920.
PROSSER, C. S., died September 11, 1916.
SEELY, HENRY M., died May 4, 1917.
WARING, CLARENCE A., died November 4, 1918.
WILLIAMS, HENRY S., died July 31, 1918.
WILLISTON, SAMUEL W., died August 30, 1918.

MEMBERS-ELECT

GLICK, PERRY A., 502 East Springfield Street, Champaign, Ill.
HENRY, LEONARD WILSHIER, Morton Street, Portersville, Calif.
HIBBARD, RAYMOND R., 450 Carlton Street, Buffalo, New York.
HOWE, HENRY V., 1514 Alder Street, Eugene, Oregon.
KEMPER, DOROTHY B., 2527 Benvenue Street, Berkeley, Calif.
MATTHEW, GEORGE FREDERICK, 115 Carmarthen Street, St. John, N. B.
MILLER, PAUL C., Walker Museum, University of Chicago, Chicago, Ill.
MOSES, FLORENCE EMMA, 5424 Claremont Avenue, Oakland, Calif.
NELSON, NORMAN E., 116 East 8th Street, Fort Worth, Texas.
NELSON, RICHARD N., 2237 Durant Avenue, Berkeley, Calif.
NOÉ, ADOLF CARL, University of Chicago, Chicago, Ill.
RICHARDS, ESTHER E., Rio Bravo Oil Company, Southern Pacific Building, Houston, Texas.
RUSSELL, RICHARD JOEL, 2412 Piedmont Avenue, Berkeley, Calif.
SLOCOM, ARTHUR WARE, Walker Museum, University of Chicago, Chicago, Ill.
STRICKLAND, FRANK PETER, JR., 640 Oakland Street, Kansas City, Mo.
TRASK, PARKER DAVIES, 1502 Alice Street, Oakland, Calif.
WALTER, OTTO F., 421 Reynolds Street, Iowa City, Iowa.
WINTON, W. M., Texas Christian University, Fort Worth, Texas.
WOODFORD, ALFRED OSWALD, Pomona College, Claremont, Calif.

Minutes of the Tenth Annual Meeting of the Pacific Coast Section of the Paleontological Society

By Chester Stock, *Secretary*

The tenth annual meeting of the Pacific Coast Section of the Paleontological Society was held in conjunction with the Cordilleran Section, Geological Society of America, at Seattle, Washington, June 18, 1920. The societies participated in the fourth annual meeting of the Pacific Division, American Association for the Advancement of Science.

The meeting was called to order by Dr. E. L. Packard in the Science Hall of the University of Washington.

As an item of business, it was moved and carried that the new officers of the Paleontological Society should be voted on by mail at a later date determined by the Secretary.

READING OF PALEONTOLOGICAL PAPERS

The following paleontological and geological papers were then read:

A STUDY OF THE FAUNA AND STRATIGRAPHY OF THE BRIONES FORMATION OF MIDDLE CALIFORNIA

BY PARKER DAVIES TRASK

(*Abstract*)

The Briones was formerly regarded as a part of the Monterey series (Lower and Middle Miocene), but the results of recent work have indicated that it is probably the lowest part of San Pablo series (Upper Miocene). The Briones deposits are found in an area of some 50 miles radius in the vicinity of San Francisco. Its sediments are chiefly sandstones, with some shales intercalated in the upper part of the formation. The thickness of the Briones varies from 500 to 2,300 feet.

There is no apparent difference in dip and strike between the Briones and the formations above and below, but there is usually a marked lithologic change, and irregular contacts with Pholas borings have been found between it and the over and under lying formations.

A study of the faunal evidence indicates a closer relation to the San Pablo than to the Monterey. Out of 70 determinable species found in the Briones, 11, or 15 per cent, extend into the Monterey, but only one of these 11 species is peculiar to these two formations, while 39 species, or 56 per cent, occur in the San Pablo, of which 19 species are peculiar to the Briones and the San Pablo. A large number of these 19 species are highly ornamented gastropods. This indicates that the Briones is probably a part of the San Pablo series. However, considering that there are 29 species, or 41 per cent, found only in the Briones, and only 6 species peculiar to the Briones and the Lower San Pablo group, and because of the stratigraphic evidence mentioned above, the

indication is that the Briones is a separate minor cycle of deposition. This would make the San Pablo series consist of three minor cycles of deposition—Briones, "Lower San Pablo," and "Upper San Pablo."

PHYSICAL AND ECONOMIC GEOGRAPHY OF OREGON

BY WARREN DU PRE SMITH

(Abstract)

The paper, which is not yet completed, though practically all the chapters are in first draft, is the result of several years' work in Oregon on the part of the author and embraces as complete a survey of the existing literature as can be found dealing with the subject. The table of contents appended will give an idea of the subject-matter. A great deal of the data in this paper has never yet appeared in print and some of the material drawn on from the literature has received new interpretation.

Among the chief points emphasized in this research is the influence of physiographic and climatic (particularly those of light and winds) features in Oregon; the part played by geographic location in Oregon's history and development. Still another theme is the matter of relationship of political and physical boundaries. The land problem in Oregon is taken up under such heads as the reserve lands, the logged-off lands, the arid lands, the undrained lands. There is a chapter on the geographic location of cities and some attempt is made to prognosticate, from a study of the geology and geography of the State, the future of Oregon's economic development.

GEOLOGY OF PALESTINE

BY REGINALD W. BROCK

LATE CENOZOIC MAMMALIAN REMAINS FROM THE MEADOW VALLEY REGION, SOUTHEASTERN NEVADA

BY CHESTER STOCK

(Abstract)

J. E. Spurr, in a paper entitled "Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California," has directed attention to the Pliocene continental deposits occupying an extensive territory in the Meadow Valley region of southeastern Nevada. The determination of age of these beds was, however, not based on paleontological evidence.

Two areas are now known in this province of Nevada where well exposed sedimentary deposits have yielded mammalian remains. The northern area comprises Meadow Valley, an intermontane inclosure bounded on the west by the Highland Range, on the east and south by the Mormon Range, and on the north by the Pioche Range. Near the village of Panaca, Lincoln County, Nevada, the deposits in which mammalian remains occur consist of red-brown and green colored sands and clays. Cross-bedded sands and gravels as well as tuffaceous materials are also present. The beds show the effect of slight folding. Several series of terraces are developed in these sediments. The mam-

malian fauna consists of a camel, possibly *Pliauchenia*, an advanced type of horse related either to *Pliohippus* or to *Equus*, and a rhinoceros. The fauna suggests that the deposits are of Pliocene age. The mammal-bearing sediments of Meadow Valley may be known as the Panaca beds.

Approximately 80 miles south of Panaca, in Meadow Valley, a second series of mammal-bearing deposits is exposed, in Muddy Valley. These beds are mapped by Spurr as Pliocene. Between the villages of Overton and Logan, Lincoln County, Nevada, and on the southwest side of the Muddy River, the deposits consist of well indurated sands and clays, red or light brown in color. They rest unconformably on a series of beds that are presumably of early Tertiary age. The mammal-bearing sediments of Muddy Valley are also terraced. In the well indurated sands and clays a small collection of mammalian remains was secured. Camels and apparently a horse are the only members of this Tertiary fauna. The forms differ from those found in the Panaca beds. The faunal difference suggests that the northern and southern deposits are not of same age. Possibly the mammal-bearing beds of Muddy Valley, which may be designated the Muddy Creek beds, are earlier in age than the Panaca deposits.

CORRELATION OF THE EMPIRE FORMATION, OREGON

BY HENRY V. HOWE

(*Abstract*)

1. The Empire fauna is Lower Pliocene in age because the Wildcat, Merced, Purissima, and other Lower Pliocene formations of California, whose position in the Tertiary is already recognized, contain many highly ornamented species of mollusca common to the Empire. Pliocene age of the Empire is indicated also by the presence of the genus *Dendraster*.
2. The Coos conglomerate, lying with irregular contact on the Empire beds, is also of Pliocene age.

OBSERVATIONS ON THE SKELETON OF THE CAVE BEAR, ARCTOTHERIUM

BY JOHN C. MERRIAM

CORRELATION AND PALEOGEOGRAPHY OF THE MARINE TERTIARY DEPOSITS OF THE WEST COAST

BY BRUCE L. CLARK

(*Abstract*)

The introduction to the paper considers the methods and principles of correlation applied to the problem of marine beds of the Pacific coast. The main part of the paper will discuss a proposed tentative correlation table, with accompanying paleogeographic maps.

GEOLOGIC OCCURRENCE OF THE HARDGRAVE JURASSIC FAUNA OF BURNS, OREGON

BY E. L. PACKARD AND R. N. NELSON

(*Abstract*)

The lower Jurassic of eastern Oregon has heretofore been known only through the meager fauna early obtained by Thomas Condon from Silvies Canyon, Harney County. The fauna was recently found to occur in a series of sedimentary and associated intrusive rocks outcropping only within the canyon of Silvies River. This series includes red impure limestone, light-colored limestone, fine-grained shale, arenaceous shale, arkosic sandstone, and basic intrusives. The fauna of nearly fifty species is mainly confined to the red impure limestone, though occasional specimens were found in the shale members. The beds apparently are dipping steeply southward and are unconformably overlain by supposed Columbia River lava.

AN ADDITION TO THE MARINE MAMMALIAN FAUNA OF NEWPORT, OREGON

BY E. L. PACKARD

(*Abstract*)

The Newport region of Lincoln County, Oregon, has already yielded teeth of *Desmostylus* sp., obtained by Condon from the beach of Yaquina Bay; a skull of *Desmatophoca oregonensis* Condon, and recently discovered cetacean remains. Stratigraphic studies make it apparent that these mammalian specimens were all derived from the Monterey Miocene, which is well exposed at Newport and which has yielded a characteristic invertebrate fauna. A nearly complete cetacean skull, lacking the distal ends of the mandibles and portions of the squamosals; a number of vertebræ, several ribs, and various elements of the pectoral girdle, including fairly well preserved scapulæ, were found in the ocean beach west of Newport. Preliminary studies indicate that this specimen should be referred to the Balænidæ, but its generic position is as yet undetermined.

TRIGONINÆ OF THE PACIFIC COAST OF NORTH AMERICA

BY E. L. PACKARD

(*Abstract*)

The oldest Trigonia fauna of the west coast of North America occurs in the Hardgrave Lower Jurassic of Taylorsville, California. The group Clavellatæ and Costatæ are represented by the two species, both of which are related to southern Asiatic forms and one of which may well be taken as ancestral to a Middle Jurassic species. The third group of the genus, the Undulatæ, is represented in the Middle Jurassic of the Cordilleran region, while the Glabræ, Scabræ, and Scaphoidea are known from the Mormon Jurassic of California. The genus is not represented in the Knoxville Cretaceous. The Horsetown and Chico faunas include 12 species and one variety, seven of which are new. One of these is considered a new variety of a Japanese species.

PECCARY FROM RANCHO LA BREA

BY JOHN C. MERRIAM AND CHESTER STOCK

(*Abstract*)

Peccary remains from Rancho La Brea indicate the presence of the genus *Platygonus*. The species is closely related to *P. leptorhinus* and *P. compressus*. It may, however, be specifically or subspecifically distinct from known North American forms of the Pleistocene.

Meeting adjourned.

ELECTION OF OFFICERS

Results of an election of officers held during October, 1920, indicate that the following selections were made:

President, Dr. E. L. Packard, University of Oregon, Eugene, Oregon.

Vice-President, Prof. B. L. Clark, University of California, Berkeley, California.

Secretary, Dr. Chester Stock, University of California, Berkeley, California.

CONSTITUTION AND BY-LAWS OF THE PALEONTOLOGICAL SOCIETY

CONSTITUTION

Article I

NAME

This Society shall be known as The Paleontological Society. It is affiliated with and forms a section of the Geological Society of America. The two societies shall, as a rule, meet together.

Article II

OBJECT

The object of this Society is the promotion of the Science of Paleontology.

Article III

MEMBERSHIP

The Society shall be composed of Fellows, Members, Correspondents, and Patrons.

1. Fellows shall be persons who have published results of paleontological research, and who upon nomination by the Council have been duly elected to fellowship by the Geological Society of America.

2. Members shall be persons not Fellows who are engaged or interested in paleontological work.

3. Correspondents shall be persons distinguished for their attainments in Paleontology and not resident in North America.

4. Patrons shall be persons who have bestowed important favors upon the Society. Election to patronship carries with it the rights and privileges of Members.

5. Fellows, Members, and Patrons are entitled to vote, but only Fellows are eligible to office in the Society.

Article IV

OFFICERS

1. The Officers of the Society are a President, three Vice-Presidents, a Secretary, a Treasurer, and an Editor.

These officers constitute an Executive Committee to be called the Council.

2. The President shall discharge the usual duties of a presiding officer at all meetings of the Society and of the Council. He shall take cognizance of the acts of the Society and of its officers, and cause the provisions of the Constitution and By-Laws to be faithfully carried into effect. The President shall also represent The Paleontological Society in the Council of the Geological Society of America.

3. The Vice-Presidents, in the order of their precedence, shall assume the duties of President in case of the absence or disability of the latter.

The three Vice-Presidents represent respectively the three chief branches of paleontology, and it shall be the duty of each to look after the interests and preside at the meetings of the section which he represents.

4. The Secretary shall keep the records of the proceedings of the Society, and a complete list of the Fellows, Members, Correspondents, and Patrons, with the dates of their election to and separation from the Society. He shall also be the Secretary of the Council.

The Secretary shall cooperate with the President in attention to the ordinary affairs of the Society. He shall attend to the preparation, printing, and mailing of circulars, blanks, and notifications of elections and meetings. He shall superintend other printing ordered by the Society or by the President, and shall have charge of its distribution, under the direction of the Council.

The Secretary, unless other provision be made, shall act as Librarian, and as Custodian of the property of the Society, except as provided for in Article IV, section 6.

5. The Treasurer shall have the custody of all funds of the Society except the fees of Fellows. He shall keep account of receipts and disbursements in detail, and this shall be audited as hereinafter provided.

6. The Editor shall supervise all matters connected with the publication of the transactions of the Society under the direction of the Council. He shall also be the keeper of all publications sent to the Society.

7. The Council is clothed with executive authority and with the legislative powers of the Society in the intervals between its meetings; but no extraordinary act of the Council shall remain in force beyond the next following stated meeting without ratification by the Society. The Council shall have control of the publications of the Society, under provisions of the By-Laws and of resolutions from time to time adopted. They shall receive nominations for Fellows, Members, Correspondents, and Patrons, and, on approval by them, shall submit such nomination to the Society for action. They shall have power to fill vacancies *ad interim* in any of the offices of the Society not otherwise provided for.

8. *Terms of Office.*—The President and Vice-Presidents shall be elected annually. The President shall not be eligible for re-election until after an interval of three years from retirement from office. A Vice-President is eligible for re-election not more than once within such interval.

The Secretary, Treasurer, and Editor shall be eligible to re-election without limitation.

Article V

VOTING AND ELECTIONS

1. All elections shall be by ballot. To elect a Fellow, Member, Correspondent, or Patron, or impose any special tax, shall require the assent of nine-tenths of all persons voting.

2. Voting by letter may be allowed.

3. *Election to Membership.*—Nominations for all classes of membership must be made by two Fellows according to a form to be provided by the Council.

One of these Fellows must be personally acquainted with the nominee and his qualifications for membership. The Council will submit the nominations received by them, if approved, to a vote of the Society in the manner provided in the By-Laws. The result may be announced at any stated meeting; after which notice shall be sent out to the elect.

4. *Election of Officers.*—Nominations for office shall be made by the Council or otherwise as provided for in the By-Laws. The nominations shall be submitted to a vote of the Society in the same manner as nominations for membership. The results shall be announced at the annual meeting; and the officers thus elected shall enter upon duty at the adjournment of the meeting.

ARTICLE VI

MEETINGS

1. The Society shall hold at least one stated meeting a year in the winter season. The date and place of this meeting shall be fixed by the Council, and announced each year within three months after the adjournment of the preceding winter meeting. The program of such meeting shall be determined by the Council in conjunction with the Council of the Geological Society of America and announced beforehand, in its general features. The details of the daily sessions shall be arranged by the Council of this Society.

2. The winter meeting shall be regarded as the annual meeting.

3. Special meetings of the Society as a whole or of any of its sections as sectional meetings may be called by the Council, and must be called upon the written request of ten Fellows, for a general meeting and of five Fellows for any of its sections.

4. The stated meetings of the Council shall be held coincidently with the stated meeting of the Society. Special meetings may be called by the President at such times as he may deem necessary.

5. *Quorum.*—At meetings of the Society a majority of those registered in attendance shall constitute a quorum. Four shall constitute a quorum of the Council.

ARTICLE VII

PUBLICATIONS

The publications of the Society shall be under the immediate control of the Council.

ARTICLE VIII

AMENDMENTS

1. This Constitution may be amended at any winter meeting by a three-fourths vote of all the Fellows, provided that the proposed amendment shall have been submitted in print to all Fellows at least three months previous to the meeting.

2. By-Laws may be made or amended by a majority vote of the Fellows present and voting at any annual meeting, provided that printed notice of the proposed amendment or by-law shall have been given to all Fellows at least three months before the meeting.

BY-LAWS

Chapter I

MEMBERSHIP

1. All Fellows of the Geological Society of America in good standing whose work is primarily in paleontology may, upon application to the Council of this Society, be elected without additional dues as Fellows of The Paleontological Society. Such Fellows, if Life Members of the Geological Society, will have no further dues to pay in The Paleontological Society.

2. No person shall be accepted as a Fellow of The Paleontological Society unless he pay to the Geological Society of America the initiation fee and the dues for the year within three months after notification of his election. The initiation fee of Fellows shall be ten (10) dollars and the annual dues ten (10) dollars, payable on or before the annual meeting in advance; but a single prepayment of one hundred (100) dollars shall be accepted as commutation for life.

The annual dues for Members shall be three (3) dollars. No person shall be accepted as a Member unless he pay the dues for the year within three months after notification of his election. The annual dues are payable to The Paleontological Society on or before the annual meeting.

3. An arrearage in payment of annual dues shall deprive a Fellow or Member of the privilege of taking part in the management of the Society and of receiving the publications of the Society. An arrearage continuing over two (2) years shall be construed as notification of withdrawal.

4. Any person eligible under Article III of the Constitution may be elected Patron upon the payment of one thousand (1,000) dollars to the Society.

Chapter II

OFFICIALS

1. The President shall countersign, if he approves, all duly authorized accounts and orders drawn on the Treasurer for the disbursement of money.

2. The Secretary, until otherwise ordered by the Society, shall perform the duties of Editor, Librarian, and Custodian of the property of the Society.

3. The Society may elect an Assistant Secretary.

4. The Treasurer shall give bonds, with two good sureties approved by the Council, in the sum of one thousand dollars, for the faithful and honest performance of his duties and the safe-keeping of the funds of the Society. He may deposit the funds in bank at his discretion, but shall not invest them without authority of the Council. His accounts shall be balanced as on the thirtieth day of November of each year.

5. The minutes of the proceedings of the Council shall be subject to call by the Society.

6. The Council may transact its business by correspondence during the intervals between its stated meetings; but affirmative action by a majority of the Council shall be necessary in order to make action by correspondence valid.

CHAPTER III

ELECTION OF MEMBERS

1. Nominations for all classes of membership may be proposed at any time on blanks to be supplied by the Secretary.

2. The form for nomination shall be as follows:

In accordance with his desire, we respectfully nominate for Fellow, Member, Correspondent, or Patron of The Paleontological Society:

Full name; degrees; address; occupation; branch of Paleontology now engaged in; work already done and publications made.

(Signed by at least two Fellows.)

The form when filled is to be transmitted to the Secretary.

3. The Secretary will bring all nominations before the Council, at the winter meeting of the Society. The Council will signify its approval or disapproval of each, and forward to the Council of the Geological Society of America all approved nominations to Fellowship.

4. At least a month before the stated winter meeting of the Society the Secretary shall mail a printed list of all approved nominees for membership to each Fellow and Member, accompanied by such information as may be necessary for intelligent voting, but an informal list of the candidates shall be sent to each Fellow and Member at least two weeks prior to distribution of the ballots.

5. The Fellows and Members receiving the list will signify their approval or disapproval of each nominee, and return the list to the Secretary.

6. At the next stated meeting of the Council the Secretary shall present the lists and the Council will canvass the returns.

7. The Council, by unanimous vote of the members in attendance, may still exercise the power of rejection of any nominee whom new information shows to be unsuitable for membership.

8. At the next stated meeting of the Society the Council shall declare the results.

CHAPTER IV

ELECTION OF OFFICERS

1. The Council shall prepare a list of nominations for the several offices, which list will constitute the regular ticket. This ticket must be approved by a majority of the entire Council. The nominee for President shall not be a member of the Council.

2. The list shall be mailed to the Fellows and Members, for their information, at least nine months before the annual meeting. Any five Fellows may forward to the Secretary other nominations for any or all offices. All such nominations reaching the Secretary at least 40 days before the annual meeting shall be printed, together with the names of the nominators, as special tickets. The regular and special tickets shall then be mailed to the Fellows and Members at least 25 days before the annual meeting.

3. The Fellows and Members shall send their ballots to the Secretary in double envelopes, the outer envelope bearing the voter's name. At the winter

meeting of the Council, the Secretary shall bring the returns of ballots before the Council for canvass, and during the winter meeting of the Society the Council shall declare the result.

4. In case a majority of all the ballots shall not have been cast for any candidate for any office, the Society shall by ballot at such winter meeting proceed to make an election for such office from the two candidates having the highest number of votes.

Chapter V

FINANCIAL METHODS

1. No pecuniary obligation shall be contracted without express sanction of the Society or the Council. But it is to be understood that all ordinary, incidental, and running expenses have the permanent sanction of the Society, without special action.

2. The creditor of the Society must present to the Treasurer a fully itemized bill, certified by the official ordering it, and approved by the President. The Treasurer shall then pay the amount out of any funds not otherwise appropriated, and the receipted bill shall be held as his voucher.

3. At each annual meeting, the President shall call upon the Society to choose two Fellows or Members, not members of the Council, to whom shall be referred the books of the Treasurer, duly posted and balanced to the close of November thirtieth, as specified in the By-Laws, Chapter II, section 4. The Auditors shall examine the accounts and vouchers of the Treasurer, and any member or members of the Council may be present during the examination. The report of the Auditors shall be rendered to the Society before the adjournment of the meeting, and the Society shall take appropriate action.

Chapter VI

PUBLICATIONS

1. The publications are in charge of the Council and under its control.

2. One copy of each publication shall be sent to each Fellow, Member, Correspondent, and Patron.

Chapter VII

THE PUBLICATION FUND

The Publication Fund shall consist of donations made in aid of publication.

Chapter VIII

ORDER OF BUSINESS

1. The Order of Business at winter meetings shall be as follows:
   - (1) Call to order by the presiding officer.
   - (2) Introductory ceremonies.
   - (3) Report of the Council (including report of the officers).
   - (4) Appointment of the Auditing Committee.

(5) Declaration of the vote for officers, and election by the meeting in case of failure to elect by the Society through transmitted ballots.
(6) Declaration of the vote for Fellows.
(7) Declaration of the vote for Members.
(8) Deferred business.
(9) New business.
(10) Announcements.
(11) Necrology.
(12) Reading of scientific papers.

2. At an adjourned session the order shall be resumed at the place reached on the previous adjournment, but new business will be in order before the reading of scientific papers.

3. At any Special Meeting the order of business shall be numbers (1), (2), (3), (10), followed by the special business for which the meeting was called.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 32, PP. 157-162 MARCH 31, 1920

PROCEEDINGS OF THE FIRST ANNUAL MEETING OF THE SOCIETY OF ECONOMIC GEOLOGISTS, HELD AT CHICAGO, ILLINOIS, DECEMBER 28-29, 1920.

J. VOLNEY LEWIS, *Secretary**

CONTENTS

SESSION OF TUESDAY, DECEMBER 28, 1920

The first annual meeting of the Society of Economic Geologists was held in Rosenwald Hall, University of Chicago, Chicago, Illinois, on December 28-29, in affiliation with the Geological Society of America.

LIST OF OFFICERS FOR 1920

President, R. A. F. PENROSE, JR.
Vice-President, E. S. BASTIN.
Secretary and Treasurer, J. VOLNEY LEWIS, New Brunswick, N. J.

Councilors:

W. H. EMMONS
H. S. GALE
WALDEMAR LINDGREN
A. C. VEATCH
H. V. WINCHELL

ELECTION OF OFFICERS FOR 1921

The officers as given above were continued, by appropriate ballot, for the year 1921.

* Manuscript received by the Secretary of the Geological Society February 19, 1921.

The sessions of the Society were called to order by President Penrose, and scientific papers were read according to the program.

PRESENTATION OF PAPERS

RELATION OF ECONOMIC GEOLOGY TO THE GENERAL PRINCIPLES OF GEOLOGY

BY R. A. F. PENROSE, JR.

NICKEL SULPHIDES AND THE POSSIBILITY OF ENRICHMENT OF NICKEL ORES

BY WALDEMAR LINDGREN

SCIENTIFIC BY-PRODUCTS OF APPLIED GEOLOGY

BY GEORGE OTIS SMITH

This paper was read by Philip Sidney Smith, in the absence of the author.

RESULTS OF EXPERIMENTAL WORK ON THE ACCUMULATION OF OIL IN SANDS

BY W. H. EMMONS AND GEORGE THIEL

ADDITIONAL NOTES ON THE ZONAL DISTRIBUTION OF DIFFERING ORES, OUTWARDLY FROM AN IGNEOUS SOURCE

BY J. F. KEMP

A BIBLIOGRAPHY OF ECONOMIC GEOLOGY

BY D. F. HEWETT

Session of Wednesday, December 29, 1920

PRESENTATION OF PAPERS

INFLUENCE OF SPACING OF OIL WELLS ON ACRE YIELD

BY ROSWELL H. JOHNSON

NOTES ON THE ORIGIN OF THE SILVER ORES OF THE COMSTOCK LODE

BY EDSON S. BASTIN

MC KEESPORT: A STUDY IN POLITICAL AND ECONOMIC GEOLOGY

BY GEORGE H. ASHLEY

CONSTITUTION AND BY-LAWS OF THE SOCIETY OF ECONOMIC GEOLOGISTS[1]

CONSTITUTION

I.—Name

The name of the Association shall be Society of Economic Geologists.

II.—Objects

The Society shall have for its objects the advancement of science of geology in its application to mining and other industries; the diffusion of knowledge concerning such application; the advancement and the protection of the status of the profession; the definition and maintenance of an adequate professional standard, and the formulation and maintenance of a code of professional ethics.

III.—Membership

The Society shall comprise members who, by knowledge, experience, and honorable standing, are qualified to advance the objects of the Society, and who shall be elected to membership as hereinafter provided.

A candidate for membership must have had eight years' professional experience, including not less than five years' work principally devoted to geology applied to mining or other industries, of which three years must have been in positions of responsibility. Graduates in geology or engineering of approved schools shall be credited as to the eight years with one-half of the time prescribed for graduation. Geologists or engineers who have rendered signal service in the application of geology to mining or other industries may also be eligible.

IV.—Officers and Council

The affairs of the Society shall be managed by a Council, which shall be elected annually by letter ballot in the manner hereinafter prescribed.

The Council shall consist of the officers of the Society named below and five other members. The officers of the Society shall consist of a President and a Vice-President, who shall be elected annually as hereinafter provided, and a Secretary and a Treasurer, who shall be elected by the Council. The offices of Secretary and Treasurer may be combined in one person by vote of the Council. The Treasurer shall disburse the funds of the Society as directed by the Council.

The term of office of the other members of the Council shall be two years. At the first election five members shall be chosen, three to serve two years and two to serve one year.

In the event of a vacancy in the Council, the remaining members of the Council may elect a successor to fill the vacancy until the next election. Members of the Council are permitted to vote by proxy.

[1] Affiliated with the Geological Society of America, by vote, on December 29, 1920.

V.—Stated Meetings

There shall be one or more meetings annually at times and places to be decided on by the Council. The winter meeting shall be considered the Annual Meeting for the election of officers and the transaction of other business prescribed for such meeting.

VI.—Rules

The Society may adopt by-laws, rules, and regulations for the conduct of its business, provided that these are in harmony with its Constitution, and may provide methods for amending or repealing such by-laws, rules, and regulations.

VII.—Admissions

A candidate for membership must be proposed by three members; and, if approved by the Council, then his name shall be submitted to a direct ballot vote of all the members of the Society, subject to final confirmation by the Council. On or after 120 days after the mailing of the direct ballot vote to the members of the Society, this final action by the Council may be taken.

In the election of members of the Society, three-fourths of all votes cast shall be required to elect; provided that if ten votes be cast against the candidate he shall be considered rejected. If any member fails to cast his vote within the specified time, his ballot shall be considered to be in the affirmative.

In the confirmation of membership by the Council a majority vote is necessary for acceptance; provided that two adverse votes in the Council may defer the acceptance, in which case the Council may again consider the candidate and vote on him for acceptance at any meeting after the lapse of one year.

VIII.—Annual Dues and Life Membership

The annual dues of members shall be $5.00, payable in advance on January 1. Life membership shall be $75.00.

If annual dues are not paid within the year to which they apply, the Secretary shall notify any one who is delinquent, and if in 120 days after the notice has been mailed the dues are not paid, the delinquent members shall be dropped from the list of members. Any such member may be reinstated by making explanation satisfactory to the Council and paying all past dues.

Funds received from the payment for life membership shall be applied to an investment fund, of which only the interest may, in the discretion of the Council, be used for the current expenses of the Society; provided, also, that the Council may have the authority, in emergencies or times of need for other worthy purposes, to draw on the principal of this fund.

IX.—Resignations

Any member not in arrears in payment of dues may terminate his connection with the Society by sending his resignation in writing to the Secretary.

X.—Discipline

The membership of any person in the Society may be suspended or terminated for reasons of weight by a three-fourths vote of the members of the

Council. Notice of such intended action shall be sent to such member by registered mail, and action shall not be taken for at least ninety days after the mailing of this notice to such member. A member suspended or expelled may demand a sealed letter ballot sustaining or reversing the action of the Council. This ballot shall be sent to all members and may be accompanied by a statement signed by the Council or a committee thereof, and by a statement on behalf of the member concerned. A majority of the votes received within ninety days after the mailing of the ballot shall be required to reverse the action of the Council.

XI.—Officers

The officers of the Society as above provided shall be elected as hereinafter provided, except that whenever a vacancy occurs it shall be filled by a majority of votes of the Council. Their respective terms of office shall begin at the close of the meeting at which they are elected. The duties of the several officers shall be such as usually attach to their respective offices, or such as may be declared by the Council. In the event of the inability of the President, either by sickness or by absence, to perform the duties of his office, the Vice-President shall act. If both the President and the Vice-President be incapacitated, a meeting of the Council at the earliest possible date shall be called by the Secretary, and a Second Vice-President shall then be named to act in the place of the President and the First Vice-President. In the event of the absence or disability of the Secretary or the Treasurer, the President may appoint an Acting Secretary or Acting Treasurer to perform the duties of these respective offices; these appointments to be subject to the confirmation of the Council at its next meeting.

XII.—Amendments

Amendments to the Constitution may be presented at a regular or business meeting of the Society, and if indorsed by the Council or signed in writing by at least ten per cent of the members, a copy of such proposed amendment shall be sent to all members, accompanied by comment by the Council, if it so elects, at least thirty days in advance of the next regular meeting. At that meeting the amendment may be changed as to wording but not as to intent, and it shall then be submitted to a final vote by sealed letter ballot sent to all members. The poll shall be open for 120 days from the date of the mailing of the ballot. For the adoption of the amendment two-thirds of the votes cast shall be required.

BY-LAWS

I.—Nominations

In all elections of officers, members shall be provided with tickets containing the nominations of at least three candidates for each office.

In advance of the annual meeting the Council shall appoint a nominating committee of three members, not more than one of whom shall be a member of the Council. This committee shall nominate three candidates for each office to be filled by election at the ensuing annual meeting, and these nominations shall be sent to the members at least 120 days before the time of the

annual meeting. To this ballot shall be added any further nomination which is proposed and supported by ten or more members; such further nomination must be received by the Council at least 150 days before the date of the annual meeting. Votes to be counted must be received by the committee of tellers appointed by the Council on or before the day previous to the first day of the annual meeting.

A plurality vote shall elect.

II.—Publications

The Council has authority, with the approval of the author of any paper presented at any meeting, to make arrangements for publishing such paper through one of the several available channels; but the acceptance of a paper for presentation at a meeting does not necessarily imply that it will be recommended by the Council for publication.

III.—Committees

The Council may provide for such temporary or standing committees as it deems desirable, and may delegate to such committees so much of its authority as it desires.

IV.—Program Committee

A special program committee shall be designated by the Council. Its duties shall be to draw up and carry out a program for meetings of the Society.

V.—Vote of Confidence

The Council, by a vote of four of its members or upon the request in writing of twenty per cent of the members of the Society, shall submit any question upon which they have passed to the membership for a vote of confidence. Such vote must be inaugurated within fifteen days after a motion for a vote of confidence has been passed by the Council or a request in writing by twenty per cent of the members of the Society has been received by the Secretary; and the majority of votes received within 120 days after the mailing of the ballot shall decide. In case such question is decided against the Council, the members thereof shall forthwith resign office, their resignations to take effect on election of their successors, and a new election of the whole Council shall be immediately ordered to be conducted as provided in the By-Laws.

VI.—Amendments to By-Laws

Amendments to the By-Laws may be proposed at any meeting of the Society or any meeting of the Council. If approved by the Council, the proposed amendments shall be submitted to the membership by letter ballot and the majority of the votes received within 120 days from the date of mailing shall pass or defeat the amendment, the result of the ballot to be effective immediately upon its declaration by the President.

January, 1921.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 32, PP. 163-170 MARCH 31, 1921

PROCEEDINGS OF THE FIRST ANNUAL MEETING OF THE MINERALOGICAL SOCIETY OF AMERICA, HELD AT CHICAGO, ILLINOIS, DECEMBER 29, 1920.

HERBERT P. WHITLOCK, *Secretary*

CONTENTS

SESSION OF WEDNESDAY, DECEMBER 29, 1920

The Mineralogical Society of America held its first annual meeting in Rosenwald Hall, University of Chicago, Chicago, Illinois, on December 29, in affiliation with the Geological Society of America.

LIST OF OFFICERS FOR 1920

President, EDWARD H. KRAUS,
University of Michigan, Ann Arbor, Michigan.

Vice-President, THOMAS L. WALKER,
University of Toronto, Toronto, Canada.

Secretary, HERBERT P. WHITLOCK,
American Museum of Natural History, New York City.

Treasurer, ALBERT B. PECK,
Bureau of Standards, Washington, D. C.

Editor, EDGAR T. WHERRY,
Bureau of Chemistry, Washington, D. C.

Councilors:

A. S. EAKLE, 1919-1920, University of California.
F. R. VAN HORN, 1919-1921, Case School of Science.

F. E. WRIGHT, 1919-1922, Geophysical Laboratory.
A. H. PHILLIPS, 1919-1923, Princeton University.

The sessions of the Society were called to order by President Kraus at 9 a. m.

ELECTION OF OFFICERS FOR 1921

The Secretary announced that the regular ballot for officers for 1921 had resulted as follows:

President, CHARLES PALACHE.
Vice-President, WALDEMAR T. SCHALLER.
Secretary, HERBERT P. WHITLOCK.
Treasurer, ALBERT B. PECK.
Editor, EDGAR T. WHERRY.

Councilors:

F. R. VAN HORN, 1919-1921, Case School of Science.
F. E. WRIGHT, 1919-1922, Geophysical Laboratory.
A. H. PHILLIPS, 1919-1923, Princeton University.
A. F. ROGERS, 1920-1924, Stanford University.
E. H. KRAUS, Past President.

PRESENTATION OF PAPERS

The presentation of scientific papers was then taken up according to the program:

FUTURE OF MINERALOGY IN AMERICA

PRESIDENTIAL ADDRESS BY E. H. KRAUS

APHTHITALITE FROM KILAUEA

BY H. S. WASHINGTON AND H. E. MERWIN

SOME SUGGESTIVE GENERAL MINERAL CHARACTERS

BY H. S. WASHINGTON

NOTE ON AUGITE FROM VESUVIUS AND ETNA

BY H. S. WASHINGTON AND H. E. MERWIN

MINERALOGY OF THE TOURMALINE MINE NEAR CANYON CITY, COLORADO

BY W. A. TARR

ORIGIN OF THE COLEMANITE DEPOSITS OF CALIFORNIA

BY W. F. FOSHAG

HYDROUS TALCS

BY W. F. FOSHAG AND E. T. WHERRY

DIAMONDS OF PIKE COUNTY, ARKANSAS

BY GEORGE F. KUNZ

LLEMONTITE FROM BRITISH COLUMBIA; SKUTTERNDITE FROM COBALT, ONTARIO

BY T. L. WALKER

NOTES ON ISOMORPHISM

BY E. T. WHERRY

ORIENTITE FROM CUBA

BY D. FOSTER HEWETT AND EARL SHANNON

MPLE METHOD OF DETERMINING REFRACTIVE INDICES OF LIQUIDS WITH THE MICROSCOPE

BY OTTO VON SCHLICHTEN

OCCURRENCE OF COSALITE IN ONTARIO

BY T. L. WALKER

CRYSTAL HABIT OF ORTHOCLASE FROM PENTICTON, BRITISH COLUMBIA

BY T. L. WALKER

MINERALOGRAPHIC STUDY OF ANIMIKITE AND MACFARLANITE FROM SILVER ISLET, LAKE SUPERIOR

BY A. L. PARSONS AND E. THOMSON

CALCITE FROM SHANGOINAH ISLAND, LAKE SUPERIOR

BY A. L. PARSONS

NEW SIMPLIFIED METHOD FOR DRAWING CRYSTALS

BY C. D. SLAWSON

SIGNIFICANCE OF CRYSTAL HABIT

BY E. T. WHERRY

HEMATITE CRYSTAL FROM MANTON, RHODE ISLAND

BY A. C. HAWKINS

The three following papers were read by title:

JURUPAITE: A NEW CALCIUM MAGNESIUM SILICATE FROM CRESTMORE, RIVERSIDE COUNTY, CALIFORNIA

BY A. S. EAKLE

FURTHER NOTES ON EAKLEITE

BY A. S. EAKLE

HOLDENITE AND CAHNITE: TWO NEW MINERALS FROM FRANKLIN FURNACE, NEW JERSEY

BY C. PALACHE

CONSTITUTION AND BY-LAWS OF THE MINERALOGICAL SOCIETY OF AMERICA[1]

CONSTITUTION

ARTICLE I

NAME

This Society shall be known as the MINERALOGICAL SOCIETY OF AMERICA.

ARTICLE II

OBJECT

The object of this Society shall be the advancement of mineralogy, crystallography, and allied sciences.

ARTICLE III

OFFICERS

The officers of the Society shall be a President, a Vice-President, a Treasurer, a Secretary, and an Editor, who shall be elected annually. There shall be an Executive Council consisting of the above officers, the retiring President, and four Fellows at large, to be elected for terms of four years each.

ARTICLE IV

MEMBERSHIP

SECTION 1. The general membership of the Society shall be composed of Fellows, Members, and Patrons. There may also be Correspondents.

SEC. 2. Fellows shall be persons who have published results of research in mineralogy, crystallography, or allied sciences, and who upon nomination by the Council shall have been duly elected to fellowship in the Society.

SEC. 3. Members shall be persons not Fellows who are engaged or interested in mineralogy, crystallography, or allied sciences.

SEC. 4. Patrons shall be persons who have bestowed important favors upon the Society. Election to patronship carries with it the rights and privileges of Members.

SEC. 5. Fellows, Members, and Patrons shall be entitled to vote in the transaction of the regular business of the Society. Only Fellows are eligible to office in the Society.

SEC. 6. Correspondents shall be persons distinguished for their attainments in mineralogy, crystallography, or allied sciences and not resident in North America.

[1] Affiliated with the Geological Society of America, as of December 1, 1920.

ARTICLE V

AMENDMENTS

This Constitution shall be amended when the proposed amendment is favored by four-fifths of all the Fellows voting upon it. A copy of the proposed amendment shall be mailed to the general membership of the Society at least thirty days before a vote is taken. Voting shall be by mail ballot.

BY-LAWS

I.—MEMBERSHIP

SECTION 1. *Eligibility.* Any person who has, in the opinion of the Council, contributed materially to the advancement of mineralogy, crystallography, or allied sciences, shall be eligible to fellowship in the Society. Any person or corporation interested in mineralogy, crystallography, or allied sciences, shall be eligible to membership.

SEC. 2. *Election.* (*a*) *Fellows.* Nominations for fellowship must be made by two Fellows according to a form to be provided by the Council. One of these Fellows must be personally acquainted with the nominee and his qualifications. The Council will submit the nominations received by them, if approved, to a vote of the Fellows in the manner provided in the By-Laws. The result may be announced at any stated meeting, after which notice shall be sent to the elected. (*b*) *Members.* Nominations for membership must be made on blanks provided by the Council, and receive the endorsement of the Secretary and Treasurer of the Society.

SEC. 3. *Termination.* Membership in the Society may be terminated or the names of the members may be placed upon the inactive list by vote of the Council.

II.—DUES

SECTION 1. No person shall be accepted as a Fellow of the Mineralogical Society of America unless he pay the dues for the year within three months after notification of his election. The annual dues for Fellows shall be five dollars ($5), payable at or before the annual meeting, in advance.

SEC. 2. The annual dues for Members shall be three dollars ($3). No person shall be accepted as a Member unless he pay the dues for the year within three months after notification of his election. The annual dues shall be payable at or before the annual meeting, in advance.

SEC. 3. An arrearage in payment of annual dues shall deprive a Fellow or Member of the privilege of taking part in the management of the Society and of receiving the publications of the Society. An arrearage continuing over two (2) years shall be construed as notification of withdrawal.

SEC. 4. A single prepayment of one hundred dollars ($100) shall be accepted as commutation for life for either Fellows or Members. In the case of Fellows, who are also Fellows of the Geological Society of America, a single prepayment of fifty dollars ($50) shall be accepted as commutation for life.

SEC. 5. Any person eligible under Article IV of the Constitution may be

elected Patron upon the payment of one thousand dollars ($1,000) to the Society.

III.—Duties of Officers

Section 1. *Officers.* The duties of the President, Vice-President, Treasurer, Secretary, and Editor of the Society shall be the usual ones performed by such officers.

Sec. 2. *Executive Council.* The Executive Council shall direct all affairs and activities of the Society not otherwise provided for by the Constitution, as well as perform those duties specifically assigned to it.

Sec. 3. *Committees.* The President shall appoint, with the approval of the Council, such committees as may further the objects of the Society, including a Board of Associate Editors. The Treasurer, the Secretary, the Editor, and the chairmen of the various committees shall make formal reports to the Society at least once each year.

IV.—Election of Officers

Nominations for office shall be made by the Council. The list shall be mailed to the general membership for its information at least three months before the annual meeting. Any five Fellows or Members may forward to the Secretary other nominations for any or all offices. All such nominations reaching the Secretary at least forty days before the annual meeting shall be printed, together with the names of the nominators as special ballots. The regular and special ballots shall then be mailed to the general membership. The results shall be announced at the annual meeting, and the officers thus elected shall enter upon duty at the adjournment of the meeting.

V.—Publications

The Society shall publish a Journal devoted to the advancement of mineralogy, crystallography, and allied sciences. The general membership of the Society shall be entitled to receive the Journal.

VI.—Affiliation with other Scientific Organizations

The Council shall have authority to arrange for affiliation with other scientific organizations and, as occasion may arise, to appoint Fellows to represent the Society on the Councils of such organizations. In the case of the Geological Society of America, the representative so appointed shall also be a Fellow of the Geological Society of America, and shall be recommended to the Council of said Society for confirmation as one of its nominees for the Vice-Presidency.

VII.—Local Sections

Local sections of the Society may be formed in any locality, with the advice and consent of the Council, for the purpose of holding meetings and promoting cooperation. The affairs of such local sections shall be entirely in their own hands.

VIII.—Meetings

There shall be an annual meeting of the Society and such other meetings as may be called by the Council. The annual meeting shall be held, whenever practicable, at the same time and place as that of the Geological Society of America.

IX.—Revision of the By-Laws

After recommendation by the Council, By-Laws may be enacted, amended, or suspended by a two-thirds vote, by ballot, of the general membership of the Society.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 32, PP. 171-186 MARCH 31, 1921

IMPORTANT EPOCHS IN THE HISTORY OF PETROLEUM AND NATURAL GAS[1]

PRESIDENTIAL ADDRESS BY I. C. WHITE

(*Read before the Society December 28, 1920.*)

CONTENTS

Ancient References to Petroleum

The date of the first use of petroleum or its residual products, pitch and asphaltum, precedes authentic history. Probably the first recorded utilization is that in the 11th chapter of Genesis, in which it is stated that the soft or semi-fluid bitumen found in the valley of the Euphrates, and translated "slime," was used as mortar in the building of Babylon more then forty centuries ago. Eratosthenes, a celebrated Grecian writer

[1] Manuscript received by the Secretary of the Society January 17, 1921.

who lived in the third century B. C., has described this bitumen from the Springs of Hit, on the Euphrates, and has also told of its use in the construction of mosaics, pavements, etcetera, in the beautiful palaces and temples of ancient Nineveh and Babylon.

Herodotus, who lived 2,400 years ago, has related how asphaltic oil was produced in his day from a lake on the island of Zante, in the Mediterranean, off the coast of Greece, by swabbing it up with a branch of myrtle, very much like the early settlers of the Allegheny and Little Kanawha valleys of Pennsylvania and West Virginia collected petroleum from the surface of water with wooden cloths; so that in the primitive methods of procuring mineral oil there is apparently "nothing new under the sun." Aristotle, who lived in the fourth century B. C., has described the deposits of bitumen in Albania, along the eastern shores of the Adriatic Sea, while Pliny and Dioscorides, who lived in the first century of the Christian era, have given an account of the oil springs of the island of Sicily and the use of petroleum in lamps under the name of "Sicilian oil." Many ancient writers and travelers, like Plutarch, Strabo, Marco Polo, and others, have recorded the use of "rock oil" and pitch in Arabia, Persia, India, and elsewhere from the earliest historic periods.

Religious Cult founded on natural Gas Springs

One of the nearly extinct religious cults, that of the Fire Worshipers, or Parsees, was founded on the mystery which the priesthood of that religion threw around the perpetual fire maintained on the altars of their temples with natural gas. When your speaker visited Baku, on the shore of the Caspian Sea, in 1897, he saw the ruins of one of these mystic shrines, the last of whose priests had disappeared only twenty-odd years before. In dismantling the altar of this ancient structure, it was discovered that it had been built over a fissure in the earth from which natural gas issued, and that a secret pipe conducted the gas from the fissure to the altar, where its lambent flames had inspired the Fire Worshipers with a belief in the supernatural powers of the priests of Zoroaster. It is possible that similar tricks of deception have imposed on the credulity of mankind during the childhood of the race in the establishment of other primitive religious beliefs.

Antiquity of Use in China and Japan

In China, whose civilization has remained practically unchanged for so many centuries, crude methods of using natural gas were practiced

more than two thousand years ago, while the Japanese have also collected and utilized mineral oil for many hundreds of years.

Hence we find that the oil and gas seepages welling up through fissures in the earth's stratified crust were both observed and used by primitive peoples of most every country.

Earliest American Accounts of Petroleum and natural Gas

The earliest written accounts of the occurrence of petroleum in America is apparently that of a Jesuit missionary, who came from Canada into New York in 1629 and wrote a letter concerning it, which was published in Sagard's "History of Canada" in 1632.

The petroleum seepages on Oil Creek, Pennsylvania, and on Hughes and Little Kanawha rivers, in what is now West Virginia, were doubtless known and used by the Indians long before white men visited the regions or Columbus landed in America. The earliest published account of the oil springs near Titusville, Pennsylvania, appears to be that of a Swedish traveler, one Peter Kalm, about 1750, while those of Wirt and Ritchie counties of West Virginia, as well as of similar seepages on the Big and Little Muskingum rivers of Ohio, were first described by Dr. S. P. Hildreth, of Marietta, Ohio, in an article published in "The American Journal of Science and Arts," New Haven, Connecticut, for February, 1826. In speaking of the flows of petroleum from the salt wells of the Little Muskingum, which interfered seriously with salt production, he says: "Petroleum affords considerable profit and is beginning to be in demand for lamps in workshops and manufactories. It affords a clear, brisk light when burnt this way, and will be a valuable article for lighting the street lamps in the future cities of Ohio."

Pennsylvania originated Petroleum Industry

Pennsylvania is generally given the credit for originating the petroleum industry, because it was on the Watson flats, near Titusville, that the first well was purposely drilled for petroleum, although, in drilling for brines, casing, jars, and drilling tools generally had all been invented by citizens of what is now West Virginia, a half century before Colonel Drake completed the historic well on the banks of Oil Creek.

West Virginia first in utilizing natural Gas

In discovering and utilizing natural gas, West Virginia clearly has precedence over Pennsylvania, for probably the first recorded reference

to this valuable fluid in the United States was made as early as 1775 [illegible] General Washington, who preempted the land around the "burning spring," nine miles above Charleston, in the Great Kanawha Valley, which he described as "A bituminous spring of so inflammable a nature as to burst forth" (take fire) "as freely as spirits and is nearly as difficult to extinguish." It is also well known that the first use of natural gas for manufacturing purposes in America was by Mr. William Tompkins in the same Kanawha Valley, who in 1841 struck a large flow of gas in boring a salt well only a few hundred feet distant from the "burning spring" that Washington had noted 66 years before and, piping the gas to his salt works, used it instead of coal in boiling down the brines, displacing several hundred bushels of coal daily. These early utilizations of petroleum and natural gas in America and many other countries of the world, however, were all meager, sporadic, and of no general economic importance.

Colonel Drake's Well the real beginning of the Petroleum Industry

In spite of the fact that these valuable hydrocarbons had been known to the human race for more than twenty-five centuries, it remained for an American, Col. E. L. Drake, of the Seneca Oil Company, to become the real founder of the petroleum industry, when, on August 28, 1859, only 61 years ago, he completed the famous well on Oil Creek, near Titusville, Venango County, Pennsylvania. This notable event in petroleum history, occurring at a time when "rock oil" was selling for $25 to $30 per barrel, soon led to a drilling campaign of wide extent, spreading to Ohio, West Virginia, and Canada in 1860, and to Russia in 1862, where hand digging of wells was carried on until seven years later, when it was supplanted by the drill, the production of Russia then rising from 37,400 barrels in 1863 to 203,000 in 1869.

Modern History of Petroleum and natural Gas divisible into three principal Epochs

The historical development of petroleum and natural gas since 1862 is naturally divisible into three periods of approximately twenty years each, characterized by different phases of progress.

Characteristics of first Epoch

The twenty years of petroleum and natural gas history from 1862 to 1883 might be termed the epoch of mechanical invention in the pro-

duction and transportation of petroleum. It was during this period that methods for deep drilling were perfected, and the fields of Pennsylvania especially were exploited and further developed, the extensions into Ohio and West Virginia not spreading far from the original developments. Transportation of oil through pipe lines and tank cars was introduced during this epoch, and refining methods were also extended and improved, while very large gas wells were incidentally discovered in drilling for petroleum.

It was near the close of this period (1882) that the Standard Oil Trust was formed, and it became the chief agent in promoting a world-wide market for American petroleum and its many refinery products.

Characteristics of the second Epoch

The next 20-year epoch of petroleum and natural gas history, beginning with 1883, was noteworthy in many respects. It marked the rise of the natural gas industry and the general introduction of gaseous fuel into domestic use throughout the petroleum fields, as well as its greatly extended use in the manufacturing industry. It was in 1883 that Spang, Chalfant & Company and Graff, Bennett & Company laid a six-inch pipe line from their iron works on the Allegheny River to a large gas well in Butler County, Pennsylvania, and, turning the same into the line, found that the rock pressure of the gas was able to force a large supply through to their factories, sufficient to take care of all their fuel needs in the smelting of billets and the manufacture of iron into the many forms of finished product. This successful experiment in the long-distance transportation of natural gas through its own expansive power rapidly led to a vast extension of pipe lines, and the natural gas industry had its birth.

It was the desire of capital to enter this field in an intelligent manner that led one great oil corporation (the Forest Oil Company, a subsidiary of the Standard Oil Company of New Jersey) to seek the advice of your speaker, who, as the result of his field-work, discovered anew the neglected and forgotten "Anticlinal Theory" of Hunt, Andrews, and Hoeffer, which he vitalized and regenerated for all time. Before this rediscovery, in June, 1882, and its later publication in "Science," the finding of new oil and gas pools in the United States beyond the boundaries of Pennsylvania, southern New York, southeastern Ohio, and the Volcano arch of West Virginia had made practically no progress.

Many wells, it is true, had been drilled in other States, but nothing of importance had resulted therefrom, since there was no consistent

theory to guide the drill in its search for the hidden treasures of oil and gas. Indeed, to such a low estate had the efforts of geologists fallen in their attempts to aid the drill in discovering petroleum and natural gas previous to the publication of the "Anticlinal Theory" by your speaker, in the issue of "Science" for June 26, 1885, and his successful demonstration of its great value in locating pools of oil and gas, that one prominent oil operator, disgusted at frequent failures of geologists to locate productive oil pools for him, was heard to remark, that if he desired to be absolutely sure of getting a dry hole he would employ a geologist to make the location. But with the new announcement of the "Anticlinal" or structural theory as a guide, the development of oil and gas spread across West Virginia into Kentucky, and passed from Ohio into Indiana on its westward march to Kansas, Texas, and Louisiana, finally reaching California and Mexico before the close of this second 20-year epoch, in 1902.

Characteristics of the third Epoch

The third 20-year epoch of petroleum and natural gas history is nearing its close. It has been characterized specially by the large production and utilization of gasoline, brought about principally through the invention of the internal combustion engine and the general introduction of liquid fuel where available for locomotive, steamship, and other industrial purposes, the Diesel engine having done for heavy liquid fuels what the general internal combustion engine has done for gasoline. The automobile and the aeroplane are only two of the inventions made practical through gasoline and the internal combustion engine. In the meantime the structural theory of oil occurrence has led to a world-wide development of oil fields. It has added Kansas, Oklahoma, Wyoming, Montana, Texas, Louisiana, California, Cuba, Haiti, Colombia, Venezuela, Guiana, Trinidad, Barbados, Equador, Peru, Argentina, and other regions of the new world, while Rumania, Galicia, Italy, Persia, British India, Egypt, Dutch East Indies, Japan, Formosa, and many other countries of the old world have yielded rich supplies of oil, the latest reports being that the domes and anticlinals of Australia as well as of the Arctic regions of America are proving rich in oil and gas. Who is there that can doubt that Africa (outside of Egypt), with its unexplored and unknown mineral wealth, will yet yield large quantities of petroleum and natural gas when its sedimentary terranes are intelligently explored.

CRITICISMS OF THE "ANTICLINAL THEORY"

In this connection it will not be irrelevant to speak of some criticisms of the "Anticlinal" or structural theory of oil and gas accumulation into pools of commercial value. Your speaker has always attributed the chief and controlling factor of oil and gas accumulation to the action of gravity. For several years many able geologists have endeavored to prove that some other force, like capillarity, for instance, has been prepotent in the accumulation of oil and gas, and that gravity operating through structure has had little or nothing to do with the matter. It has always been observed, however, that when these critics of the "Anticlinal Theory" go into the field to search out possible oil and gas territory upon which they would advise their clients to spend money in a search for these fugitive minerals, they invariably select the most prominent anticlinals and domes they can find within the regions considered worthy of exploration.

In the Journal of Geology, volume 27, 1919, pages 252-262, Mr. A. W. McCoy, under the title of "Notes on principles of oil accumulation," attempts to show from small laboratory experiments that the main potent factors operating to accumulate oil and gas into pools of commercial value are those due to capillary forces, and that the sole effect of "anticlinal structure" on such accumulation is the development of faults, fractures, or minute fissures parallel to the anticlinals, through which alone oil and gas can pass to higher levels, thus relegating gravity or the buoyancy of oil and gas to the scrap-heap of exploded theories, so far as playing any effective part in the accumulation of oil and gas pools is concerned.

However, some inquiring minds were not satisfied with the character of Mr. McCoy's experiments and regarded them as inconclusive. Among this number was Mr. R. Van A. Mills, of the U. S. Bureau of Mines, that great government institution which, along with the U. S. Geological Survey, has done so much for the oil and gas industry, and to the successful founding of which a distinguished Fellow of this Society, the late Dr. Joseph A. Holmes, yielded up his useful life, quite as great a hero as any who fell on "Flanders Fields." Mr. Mills has given in Economic Geology, volume XV, number 5, July-August, 1920, pages 398 to 421, under the title of "Experimental studies of subsurface relationships in oil and gas fields," a preliminary announcement of the results of his elaborate experiments, with adequate equipment and simulating as closely as possible the subsurface conditions to be found

in every oil and gas field. By means of these experiments he not only demonstrated the overwhelming preponderance of gravity as the principal factor in oil and gas accumulation, but proved the minor part played by capillarity. The "Anticlinal," or gravitational, theory for oil and gas segregation into valuable pools having always been insisted on by your speaker as the main and controlling factor, it is with considerable satisfaction that, after many assaults by able but mistaken geologists, the buoyancy theory has been so signally sustained through these exhaustive and demonstrative experiments of Mr. Mills, whose results are briefly set forth in his concluding summary as follows:

Summary of R. Van A. Mills' Results

"To enumerate the various relationships indicated by the investigations herein described would require a longer paper than is appropriate at this time. Consequently, in addition to the conclusions from the experiments, the present contribution is summarized by a statement of a few of the broad facts and relationships that have been established.

"One of the most important things to be realized is that all of the phenomena observed in the laboratory, as well as in the field, are brought about through the influence of various factors with different effects. In other words, we are obliged to deal with the summation of the effects of many factors, not with the effect of any single factor. The values of the different factors that influence the migration, accumulation, mode of occurrence, and the recovery of oil and gas are extremely variable and are relative one to another. Different factors have predominating influences according to the different sets of limiting conditions into which enter, collectively, the porosities, fineness of pores, textural variations, and degrees of dip of the sands, the qualities of the fluids, more especially the viscosities of the oils, the degrees of saturation of the strata by water and oil, the temperatures, pressures, and many other conditions. Thus, it is recognized that there is a wide range of variation in the nature and extent of induced movements, especially the differential movements of gases, oils, and waters upon which recovery, together with the effects of water upon recovery, very largely depend. It is further recognized that gas mixed with oil facilitates lateral as well as vertical migrations of oil in water-bearing strata. Again, it is recognized that there may be a limit to the fineness of water-filled interstices beyond which viscous oils do not appear to migrate 'gravitationally' under ordinary conditions. It is further recognized that in a medium-grained, water-saturated sand a single globule of oil fails to migrate 'gravitationally,' but as more globules of oil are added to it, there is formed an aggregation of globules whose cumulative buoyancy is sufficient to overcome the resistance to upward migration. Such relationships are important in the consideration of up-dip migrations. We must keep constantly in mind the critical conditions up to which certain phenomena hold true, but beyond which there are absolutely different phenomena.

"The field and laboratory investigations that the writer has so far made indicate that under ordinary field conditions the up-dip migration of oil and

gas under the propulsive force of their buoyancy in water, as well as the migration of oil, either up- or down-dip, caused by hydraulic currents are among the primary factors influencing both the accumulation and the recovery of oil and gas.

"The terms 'up-dip migration' and 'down-dip migration,' as used in this paper, apply to migrations that are in accordance with the configuration of the tops of the sands, regardless of actual structures. It must be remembered that there are many subsurface conditions, such as the domelike tops of lenses, irregularities in the tops of sands, and irregular textural barriers, which bear no consistent relations to structure, but whose influence upon oil and gas accumulation are analogous to those of true anticlines and domes. The writer's remarks apply to these conditions which he terms structural analogies.

"In concluding this paper, the writer calls attention to the views recently set forth in the literature,[2] that the migration and accumulation of oil in water-saturated strata are caused mainly by capillary forces: that oil does not migrate up the dip, due to the difference in specific gravity between oil and water, and that oil is not propelled through sand by hydraulic currents. It is further maintained that oil has been forced out of the fine bituminous shales adjacent to the reservoir rocks by the capillary action of water, and that no wide lateral movements of oil have subsequently taken place.

"The writer can not accept these views as generalizations. They may appear to hold true under exceptional conditions, as in small-scale laboratory experiments, where the conditions of experimentation are especially favorable to the hypotheses, but they do not generally hold true, either in the laboratory or in the field. Capillary adjustments between oil and water in saturated strata are restricted within short lateral ranges, amounting to only a few centimeters in the writer's experiments. The principal rôle of capillary, in saturated strata, is to retard rather than to promote fluid movements."

This thorough and careful investigation and experimental proof of the preponderance of gravity in oil and gas accumulation, as well as the demonstration of the very small effect of the capillarity factor, should dispose once for all of the claims that capillarity has played the principal rôle in the movement of oil and gas into pools of commercial value.

VALUE OF PETROLEUM FOR MARITIME FUEL

It was during the present 20-year epoch that the maritime nations of the world have realized the great value of liquid fuel, not only in the arts of peace, but also in the arts of war. Some one has well said that during the late World War "The navies of the allies floated to victory on a sea of oil." The lessons of the war with respect to the use of

[2] A. W. McCoy: "Notes on principles of oil accumulations." Jour. of Geology, vol. 27, 1919, pp. 252-262.
W. F. Jones: "The relation of oil pools to ancient shorelines." Economic Geology, vol. 15, 1920, pp. 81-87.

liquid fuel in naval warfare were so impressive to Great Britain and France that they did not even await the termination of that titanic struggle before sending their shrewdest representatives in statecraft to Persia to secure the Anglo-Persian treaty excluding all but their own nationals from any participation in the development and exploitation of these potentially great oil fields. Dr. George Otis Smith, the distinguished Director of the U. S. Geological Survey, and his able Chief Geologist, Dr. David White, have sounded a note of alarm which has finally induced our State Department to protest these exclusive treaties. This protest should have been made long ago, before the close of the war, when our wishes would have met with instant attention. It is to be hoped that the new administration that the people have so unanimously called to the helm of state after March 4 next will see to it that the control of this great industry founded by American genius and initiative, which gave to all the people of the earth a cheaper and better light, whose radiant beams have illuminated every household of the world, shall not pass to other hands except through fair and legitimate competition, and that a treaty concluded with Persia while America was putting all of her resources at the command of Great Britain to save both Britain and France, as well as civilization, from destruction shall not be permitted to shut out our nationals from any share in the development of these rich foreign fields, while we at the same time permit the English, the French, and the Dutch to own and operate any of our lands for oil and gas in every portion of the United States, and of which liberal treatment all these nations are taking great advantage.

Peak of Production reached

It is altogether probable that the peak of oil production in the United States has either been attained during the present year or will be reached in 1921. The peak of natural gas production was passed in 1917 and is rapidly declining on its long downward path to inevitable extinction. In spite of the vast waste accompanying its introduction, it has accomplished a useful purpose in educating many millions of people to the cleanliness and convenience of gaseous fuel. Hence, when natural gas is no longer available, its place will be largely supplied by manufactured gas derived partially from by-product coke ovens, the gas from which source was formerly consumed in the wasteful beehive oven process of making coke, along with other products of immense value that are now being recovered and utilized.

EXHAUSTION OF PETROLEUM

However, all agree that, with the vast increase in the use of liquid fuel through the automobile, the aeroplane, the truck, the farm tractor, the locomotive, and the ship, even the present enormous supplies of petroleum will soon fail to meet the ever-increasing demand for this convenient form of power. Whither shall our nation turn for a substitute? Fortunately dame Nature has been extremely provident to the United States. In addition to giving her very large and rich oil and gas fields, she has endowed her with approximately one-half of the coal supply of the world, as also with enormous quantities of bituminous shales, out of which both gaseous and liquid fuels can be extracted in much greater volume than those yielded to the drill from old mother Earth. The mountains of oil shale in Colorado, Wyoming, and Utah, together with the coal beds and bituminous shales of nearly every State in the Union, stand ready to yield up their content of oil and gas through intelligent chemical and metallurgical treatment when the natural sources no longer furnish an adequate supply of these convenient (oil and gas) hydrocarbons. Therefore, with the fall of our mountain streams and cataracts utilized in electric current for transporting our railway trains over and under our hills and mountains, as also for many other uses of light, heat, and power, in order to husband our vast carbon resources, Americans can face the future with every assurance that their heritage of fuels and water-power, if intelligently utilized and conserved, will be sufficient to supply all of the necessities of civilization to a far distant future. There has been a fear that with the disappearance of our petroleum no practical substitute for gasoline could be found. Such fears overlook the fact that from every ton of bituminous coal two and one-half to three gallons of benzol can be extracted in the by-product coking process, an even more efficient motor fuel for automobiles, tractors, aeroplanes, etcetera, than gasoline, while by the carbocoal" [3] process recently put into successful operation at Irvington, New

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[3] *DESCRIPTION OF CARBOCOAL PROCESS*

The carbocoal process includes three distinct stages:

1. Primary distillation.
2. Briquetting.
3. Secondary distillation.

In the process the by-products are recovered from the gas of both distillations.

Primary distillation.—The initial step in the carbocoal process is a continuous low temperature distillation. The coal to be carbonized is first ground to one-fourth of an inch or smaller and then delivered to the primary retorts, where it is distilled at a rela-

Jersey, on a small scale and at South Clinchfield, Virginia, on a large scale, by the International Coal Products Corporation, not only is a substitute for anthracite produced from bituminous coal, as briquets, but from each ton thereof 30 gallons of tarry and oily residues are derived, from which 15 to 20 gallons of marketable oils can be obtained, all of which are available for liquid fuel, and also two to three gallons of light oil that can be stripped from the resulting gases before the latter are used as a source of heat in the manufacture of the carbocoal briquets. Hence, while the increasing use of liquid fuels may outstrip the production of petroleum in the near future, yet with the vast reserve that must exist in the unexplored and undeveloped regions of the earth and the

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tively low temperature, 850° to 900° Fahrenheit, the volatile content of the coal being reduced to approximately 8 per cent. The result of this primary distillation is a large yield of tar, gas of a high thermal value, and a product rich in carbon, called "semi-carbocoal."

The characteristic feature of the primary distillation is that it is continuous, and that the coal is constantly agitated and mixed during the entire operation. This is accomplished by a twin set of paddles, each revolving slowly, in opposite directions, and so pitched as to advance the charge through the retort. By this means all portions of the charge are uniformly distilled, and by controlling the speed at which the charge moves through the retort the distillation may be carried to any desired stage. Due to the low temperature of distillation and to the partial carbonization in the primary ovens, the hard metallic cells characteristic of coke are avoided. The period of this distillation is from two to three hours, and each retort has a carbonizing capacity of 24 tons or more of raw coal per day.

Briquetting.—The semi-carbocoal, after being discharged through the primary retort, is ground and mixed with a certain proportion of pitch, obtained from the tar recovered in the process, and this mixture is briquetted.

Secondary distillation.—The briquets coming from the briquetting plant, which are termed "raw briquets," are delivered to the secondary retorts, where they are subjected to an additional distillation at a higher temperature, approximately 1,800° Fahrenheit, resulting in the production of "carbocoal," the recovery of additional tar and gas, and a substantial yield of ammonium sulphate.

In the secondary distillation, pitch as a separate ingredient of the raw briquet disappears. There is a marked shrinkage in the volume of the briquet, with a corresponding increase in density, but no distortion of its shape. This distillation requires about six hours and is performed in an incline retort, using gravity charge and discharge. The capacity of these retorts is approximately 60 tons of raw briquets per day.

The "carbocoal," which is the final product, represents approximately 70 per cent of the weight of the raw coal, the exact percentage depending on the volatile content of the coal.

The process is self-contained—that is, it produces sufficient gas and in most cases an excess over and above that required for carbonizing purposes.

PRODUCTS FROM PROCESS

From careful measurements made with Pittsburgh and Clinchfield coals containing approximately 35 per cent volatile matter, and confirmed by numerous tests of other coals containing a similar percentage of volatile matter, the following average yields from one net ton of coal have been obtained:

65 to 70 per cent of carbocoal briquets.
15 to 20 gallons of tar oil products.
20 pounds of sulphate of ammonia.
2,000 cubic feet of surplus gas (550 B. T. U.).

enormous amount of potential oils that are locked up in our coals and bituminous shales, to be released at the bidding of our chemical engineers, there would appear to be no cause for immediate alarm over any possible shortage of oils or motor spirits in the near future.

Origin of Petroleum

With reference to the origin of petroleum and natural gas, geologists appear to be generally agreed that their source must be found in organic life, either directly or indirectly. The fact that no commercial accumulations of either are found outside of marine beds, except where these accumulations have clearly come up from marine beds below, would point to the sea as the ultimate source of the organisms or raw material from which these hydrocarbons were derived. Whether the petroleum and natural gas as we find them stored in porous sedimentary strata originated directly from the decomposition of marine plants and animals, or whether they originated from the subsequent slow distillation of the kerogen produced in the shales from the imbedded organisms, is a question not yet fully determined and possibly never may be settled beyond cavil, although the preponderance of present evidence would point to the kerogen distillation at a low temperature as the immediate source.

Master Mind of the Standard Oil Company

This imperfect sketch of petroleum and natural gas history can not be closed without special reference to the conspicuous part played in this history by one of the great captains of the American petroleum industry. One of the very few men who founded the Standard Oil Company has taken such a leading position in petroleum history, as well as in the general industrial history of the world, that any sketch of oil and gas history without special reference to his part in the greatest business success of the ages would be very incomplete. The master mind of the Standard Oil Trust was John D. Rockefeller, of Cleveland, Ohio. Born in Richford, Tioga County, New York, July 8, 1839, he came with his parents to Cleveland in 1853, where, after completing a two years' course in high school and a summer's course in a commercial school, at the age of 16 he began his remarkable business career as an employee in a commission house at a salary of $4.00 a week. Here his faithful work and native talent soon brought a promotion to cashier and bookkeeper, with increase of salary to $700 a year. At the age of 19 he had saved up $1,000 and concluded to go into the commission

business himself, after borrowing another thousand from his father. Starting on his business career in 1858 with this modest capital, the fruit of his boyhood thrift and savings of three years, his meteoric business progress from this simple beginning to that of the richest man in the world illustrates in a striking way how, under the freedom of American institutions, not only the "rail-splitter," the "tanner," or any other class of common laborer may rise to the Chief Magistracy of the Nation, but that the poor boy may become the richest citizen of the world through his own unaided genius and initiative.

The very next year after Colonel Drake had discovered a method of securing from the earth large quantities of petroleum young Rockefeller had the vision to foresee the possibility of furnishing the world with a new, better, and cheaper light than the tallow dip then universally in use. Hence, entering the refining business in 1862, only three years after Colonel Drake's discovery, his name and the business organizations founded principally through him have been inseparably connected with the history of petroleum and natural gas ever since.

Sanctity of private Property the only Path to Progress

It has been only a short time since it was quite the popular thing for some men of narrow vision and superficial acquaintance with the practical business affairs of life to sneer at such men as Mr. Rockefeller, whose wealth has been accumulated so largely from industries founded upon petroleum and natural gas, and even to advocate the rejection of any philanthropic gifts, as "tainted money," when proffered by men who had through foresight, industry, and thrift accumulated large fortunes. The business success of Mr. Rockefeller represents the American theory of the sancity of private property, the greatest incentive to individual effort and the general progress of civilization, as opposed to Bolshevism and Communism, which regard all privately owned property as but another name for theft, and which would have the State take over and either redistribute all private fortunes or possess them for the benefit of not all, but of a class (the proletariat), after the capitalists had been dispossessed and drived out or killed. This latter theory of government and property, fortunately for the future progress and stability of civilization, has recently been put to the test of actual trial on an enormous scale, involving the destinies of more than one hundred million of the human race. Lenin and Trotzky have had unlimited opportunity to make a practical test of the Communistic theory, that all privately owned property represents robbery of the poor, and that every-

thing, including men, women, and children, should be nationalized. What are the results? Let torn, bleeding, starving anarchistic Russia answer as to the outcome of dividing up accumulated wealth and property among the masses. Let her idle factories, whose foremen and experts have either been murdered or driven into exile; her uncultivated and grainless fields; her unemployed and starving professors and educated classes; her murdered citizens of the frugal and property-owning class; her lust-corrupted school children of both sexes; her communized and violated women; her enslaved and terrorized laborers, ruled by a despotism more cruel and heartless than even that of Ivan the Terrible, answer as to the merits of Red class rule of the proletariat compared to that of our free and glorious democracy, where the accumulation of privately owned property by thrift, industry, and sacrifice is not yet regarded as criminal by the large majority of American citizens.

This great university, under whose sheltering domes our scientific societies meet—its stately and beautiful temples, in which the accumulated knowledge of all time finds such splendid exposition by hundreds of learned minds—could not have been called into existence except for the business foresight, the master minds to grasp the possibilities of the petroleum industry, which, through labor and sacrifice, thrift and endurance, Mr. Rockefeller and his associates carried forward to commercial success in every quarter of the world. This university, the Rockefeller Foundation, the Rockefeller Institute for Medical Research, the Laura Spelman Rockefeller Memorial, Mr. Rockefeller's latest gift of $63,000,000 for charitable purposes, the countless benefactions to colleges, universities, churches, and to every cause worthy of human endeavor, totaling the enormous sum of five hundred millions, as Mr. Rockefeller's present contribution to human welfare, should be a sufficient answer to those who would overturn our present private property system and substitute therefor any kind of communistic government. The example of Russia on a large scale and that of William Lane in Paraguay on a small scale give the same answer; the end of both is idleness, starvation, crime, and barbarism.

It is to be hoped, in view of these two conspicuous failures of Communism to alleviate the ills of mankind, that all thinking minds, especially in our colleges and universities, whose teaching staffs have not been entirely free from the delusion which Karl Marx did so much to promote, will abandon forever the idea of State Communism as a cure-all for poverty, crime, and all the other ills that have always afflicted humanity and always will, so long as envy, jealousy, greed,

cruelty, and other vicious principles in human nature remain the common inheritance of the race. The little attention yet given to eugenics by the vast majority will evidently postpone to a very remote future the day when all the wolfish propensities shall disappear from mankind, and until that day dawns it would appear to be the part of wisdom and the only path to progress to preserve inviolate the sanctity of private property, the keystone on which all present civilization rests.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

ORIGIN OF SOUTH AMERICAN FAUNAS[1]

PRESIDENTIAL ADDRESS BY F. B. LOOMIS

(*Read before the Paleontological Society December 29, 1920*)

CONTENTS

RELATIONS OF EARLY VERTEBRATES TO PLANTS

The background against which the early history of the South American animals unrolls includes the food supplies, the climate, and the migration possibilities. The time when the various groups begin to assume modern aspects and when the mammals begin to flourish is the latter part of the Cretaceous and the beginning of the Eocene.

The prime influence controlling any group of animals is the food supply. While the origin of mammals goes at least back to the Comanchean, it is not until the Eocene that they flourish and spread out into luxuriant lines of adaptation. The evolution of flowering plants started in a manner which, to those of us who study mostly mammals, is strange; for the early angiosperms are trees of considerable size, while the herbaceous plants coming later are smaller by far. Just before the beginning of the Eocene, sedges and grasses spread over the arid country, but it is not until the Eocene is really begun that the modern luxuriance of vegetation is characteristic, when the heretofore wind-pollinated trees and grasses adapt themselves also to insect fertilization. Thus, then, just about the beginning of the Eocene, to the forests is added a carpet of grass on the prairies, ponds and streams are bordered and even occupied by soft herbs, mountain slopes up to the snow-line blossom with both

[1] Manuscript received by the Secretary of the Society March 3, 1921.

grasses and succulent leaves, and even the deserts find types which can grow under their unfavorable conditions.

All animals depend on plants for their food supply. In the water it is microscopic types like algæ, diatoms, and desmids which are the ultimate source of food for the teeming life of oceans, lakes, and rivers; but on land it is the higher flowering plants which furnish the animal food. While amphibians gained some of the advantages of land life, they were not only unable to lay an egg which could develop in the air, and so have to come back to the water for breeding, but they also were unable to utilize land plants for food, as must be concluded on looking over the range of their adaptations, from their universally carnivorous dentition. These first land vertebrates, then, must have depended ultimately on the microscopic plants of the water; for, while some might have fed on other amphibians, these had to depend on fishes, which in turn ultimately depended on the water plants. In like manner the early reptiles, while they advanced so that they could breed on land, are still all carnivorous; so their food supplies must ultimately have been aquatic, this in spite of the fact that forests of great trees covered the lowlands and swamps. Just why ferns, sigillarians, calamites, gymnosperms, etcetera, did not appeal to the early land animals, I do not know, but it is striking that our early amphibians and reptiles are all carnivorous. In the Cretaceous we find a part of the dinosaurs taking vegetable food of land character. These forms flourished just when the first angiosperms, like birch, beech, maple, plane, sweet-gum, and breadfruit-trees, were coming into dominance; and, of course, these dinosaurs became the food supply for the large carnivores. So, then, it is not until the Cretaceous that any of the vertebrates became fully adapted to land life.

Among these great reptiles, even back to Comanchean time, there are mammals, small, and the first ones essentially carnivorous or perhaps insectivorous. Matthew has suggested that the start of mammalian development was in the trees,[2] and has given various anatomical reasons for this belief. It seems to me probable, and at first the food of these tiny forms was probably insects which got their food from land plants. In the trees the early mammals were also where seeds were most accessible, especially when green and soft; but it was not until herbaceous plants with seeds rich in starch begin to appear in abundance that the mammals increase in number, variety, and size. They are the first class of vertebrates which turned directly to that great unutilized supply of food, and this made suddenly possible a tremendous increase in the vertebrate life on land.

[2] W. D. Matthew: Am. Nat., 1904, vol. 38, p. 811.

Land Connections of South America

After the great and isolating submergences of the mid-Cretaceous, the late Cretaceous is a time of uplift, when we had a remarkable set of land connections, North America with Asia and South America, Europe with Africa, and Asia with Australia. The union of western North and South America continued into the early Eocene to just about Wasatch time. Then the Central American connection was submerged, and South America was isolated until the Upper Miocene at least, the mingling of North and South American faunas taking place in the Pliocene. During this long period of insular conditions South America developed a rich and varied mammalian fauna, one of the most distinctive ever developed on any continent. While South America was isolated, North America and Eurasia (connected from time to time) developed our modern advanced types of mammals. I can find no convincing evidence that during this time South America received any real migration from the outside; therefore it is to such types as were already in South America at the beginning of this period that we must look for the progenitors of the marsupials, edentates, litopternas, typotheres, toxodonts, primates, etcetera.

Comparison of Eocene Faunas of North and South America

At the beginning of the Eocene, South America was connected with North America and evidently with no other continent. The earliest mammalian fauna in South America is the Notostylops fauna of Eocene age. It includes marsupials, edentates, toxodonts, litopternas, typotheres, and probably primates. To consider these more closely, let us take first the marsupials.

There are true didelphids in the Notostylops beds and all through to modern times, in South America, in North America, and in Europe. Another group, generally termed sparassodonts, includes large carnivorous marsupials, ranging in size up to Borhyæna, nearly as large as a bear. These are close to Thyalocinus, the Tasmanian wolf, so close that Sinclair put them in the same family. Some have postulated convergence in evolution for these forms from the Santa Cruz, Deseado, and Notostylops beds. I can not see that they diverge, as they are followed backward. A group of tiny marsupials is today represented by Cænolestes. It has been called a pseudo-diprotodont, supposed to be independently derived from some didelphid; but the Santa Cruz genera Garzonia and Halmarhippus, the Deseado Pseudo-halmarhippus, and the Notostylops Progarzonia carry the diprotodont characters back to the oldest South American beds. Besides, there are other diprotodonts, such as Palæothenes, Pilchena, and Abderites. It looks to me as if we must recognize that several of the

marsupial families had become differentiated as early as the beginning of the Eocene. We are already used to thinking of the opossum family as distinct at the beginning of the Eocene. The Thyalocines must also have been distinct, and have been in North America in the early Eocene, and I anticipate representatives of the family will turn up in the Fort Union. The Diprotodont division of marsupials must thus early have been established.[3] Gidley, after describing the skull of Ptilodus, concludes that the Allotheria and Multituberculata are marsupials related to, though not ancestral to, the diprotodonts, the two groups having an ancestry still further back.[4] Last winter, on making a further study of Pyrotherium, I was convinced that its relationship was with Diprotodont, making it a marsupial instead of an elephant, as I earlier thought. In the early Eocene, then, we have didelphids, allotheres, and plagiaulicids common to both continents. In South America there are sparassodonts, cænolestoids, and pyrotheres as yet not found in North America. On the other hand, North America developed creodonts to take the place occupied by sparassodonts in the south.

Turning to Edentata (Xenarthra only), we find members of this order represented by teeth and scutes in the Notostylops beds. The Torreon and Puerco of North America yield several genera (Psittacotherium, Onychodectes, Conoryctes, etcetera) which Wortman united as Ganodonta, making clear that they belonged to the edentates. This would indicate that the order originated in Cretaceous time and was in both North and South America in the early Eocene. In North America it slowly died out by the end of the Eocene represented by such genera as Calamodon, Stylinodon, and Metacheiromys; in South America, on the other hand, they become a little more abundant in the Oligocene, and then in the Miocene suddenly increase in numbers, variety, and size, diverging into the armadillos, ground-sloths, and glyptodons until over half of all finds in these and later beds belong to this group. When the Americas united, in the Pliocene, they migrated to North America in numbers sufficient to make a real element in the fauna of the Pliocene and Pleistocene, but they were in company too fast for them and have all died out on this continent. At the same time our types of carnivores moved to South America, and, though more slowly there, the edentates gave way; so now only diminutive remnants of that great fauna are left in a few armadillos, sloths, and ant-eaters.

The rodents offer one of the most puzzling problems as to their origin in South America. No rodents are found in the Paleocene of North America.

[3] Gidley has recently described a pouched ant-eater from the Fort Union, assigning it to the same genus, Mymecobius, as the form living today in Australia. Proc. U. S. National Museum, 1915, vol. 48, p. 395.

[4] Gidley: Proc. U. S. National Museum, 1909, vol. 36, p. 611.

They appear as full-fledged rodents of the squirrel family in Paramys, in the Wasatch beds. None of this type reached South America before the Pliocene. In an equally sudden manner Hystricomorphs appear in the Oligocene (Deseado = Pyrotherium) beds in South America. The first forms belong mostly to the genus Cephalomys; in the Miocene there are four families represented, and today six, cavies porcupines, chinchillas, capybaras, etcetera. Hystricomorphs are also known from the Oligocene of France and Africa, those from France being the older. In some way they got to South America. It is the only group for which a land bridge would need to be postulated, and on this alone few of us would want to postulate such an earth's upheaval, for over it would have come or gone no other forms.

The North American Palæocene has yielded but few Primates, Indrodon being the best known. Ameghino described a large number from the Notostylops beds, but most of them have since been assigned to the Typotheres. Undoubted primates begin in the Colopdon beds (early Oligocene) in Clenialites, which is followed by the well known Homunculus in the Miocene, a typical member of the Cebidæ. In later beds they increase in size, and today two families of South American primates are recognized, the Cebidæ and marmosets, the two being usually united with the Old World monkeys to make the Anthropoidea. To my mind, this is a misleading classification, for the South American Primates diverged from the Old World Primates in basal Eocene times and have never since gotten farther from their homeland than Central America. The independent history of these two phyla should be recognized in their nomenclature, these New World forms being as much pseudo-monkeys as the litopternas are pseudo-horses.

So far the discussion has referred to less than half the Notostylops fauna. The rest of it is herbivorous and is usually designated as Notungulata, including the litopternas, typotheres, toxodonts, astrapotheres, and homalodotheres. At the beginning of the Eocene, North America also had its group of herbivores, the collective assembly grouped as Condylarthra. The Notostylops fauna includes a large number of such types as Didolodus, Othneilmarshi, Asmithwoodwardi, and Lambdaconus, which are so like the Condylarthra that Ameghino (I think correctly) has placed them in this order. Though the material is fragmentary, there can be little doubt that these two groups had a common ancestry. From this first herbivore group arose in North America the Perissodactyls and Amblopoda, the one grass-eaters, the other browsers. Similarly, in South America there came from the common group different phyla adapted to different types of vegetation.

The grazers made a very progressive series, running through Deutero-

therium, Notodiaphorus, Prototherium, Diadiaphorus, and Thaotherium, the pseudo-horses. There was also a less progressive line, Portheosodon, Theosodon, and Macrauchenia, the two lines making the litopternas. These roughly parallel the Perissodactyls of North America and indicate that, given similar material in similar environments, parallel evolutionary lines result.

Again, in the Notostylops beds there is a group of teeth, Pantostylops, Trigonostylops, Albertgaudryi, etcetera, which resemble the teeth of Amblypoda so strongly that Ameghino assigned them to this group, and from them traced first a line through Astraponotus, Parastrapotherium, Astrapothericulus to the aberrant Astrapotherium. It is a distinct line of development similar to that leading to Uintatherium in North America, and the forms should be given either ordinal or subordinal rank, according to the treatment given to other similar lines. The Homalodotheres, with their heavy build, broad feet, and cleft toes, run through such forms as Asmodeus and in like manner represent a line of development. All these forms are pretty clearly derived from condylarth stock and should be grouped together.

In regard to the typotheres and toxodonts, it seems to me they represent a separate group. The two lines are already distinct in Notostylops time. One line runs through such forms as Notostylops, Rhynchippus, Leontinia, Nesodon, and Toxodon, the toxodonts; the other includes Notopithecus, Archæohyrax, Hegetotherium, Pachyrucos, and Typotherium, the typotheres. In the two groups the ground plan of the teeth is the same. The feet of the typotheres are the less specialized, but neither advanced beyond the three-toed condition. Both early developed a high degree of hypsodonty, and to my mind were grass-eaters; but at the same time there is something unguessed about their habits, for they are too slow and clumsy for prairie animals. The plan of their teeth could well come from the Condylarth type, but they seem to have separated off earlier than the litopternas, etcetera.

There is left but Necrolestes, called by some an insectivore, close to the Cape golden mole, at the same time compared to the marsupial mole, Notoryctes. It may be an insectivore, but if so it is the only representative of the order found fossil in South America. The auditory bulla, which would settle the question of its affinities, is lacking. Personally I am inclined to think it is a specialized marsupial.

From the above we can pretty confidently look to North America at the beginning of the Eocene for the origin of all the South American mammals, rodents excepted, and to the isolation of the continent we can attribute the specialization of their development. The only group which has suggested the need of a land bridge is the hystricomorph rodents

which arrived in the Oligocene. This I do not feel would at all justify postulating such a land connection in Tertiary time.

Review of Gondwanaland Data: Reptilian, Fish, Land Snails, and Flora

However, there is a well established tradition that there was a land bridge from Africa to South America through Permian, Triassic, Jurassic, and Cretaceous time, making South America a part of the continent termed Gondwanaland. Let us look at the evidence on which this is based. Among other groups, it has been used to explain the distribution of fresh-water fishes, land snails, mussels, crayfish, and the Glossopteris flora. These are not all the groups for which it has been postulated, but in these the best arguments have been built up. Vaughn's studies[5] on Central American invertebrate faunas yield this in regard to the connections of North and South America: "During Jurassic and Cretaceous there was no connection between the Atlantic and Pacific oceans across Central America"; and, further, but no longer quoting, during Triassic and Permian there were land conditions through Mexico and Central America, with but one interoceanic connection in the Triassic. This being the case, there was always open the possibility of migrations to and from North America during almost all of the period postulated for Gondwanaland.

First let us look at the reptiles, of which South America has yielded but a scant supply. However, there are three genera of theropod and three of sauropod dinosaurs which Lull[6] in his distribution of dinosaurs has piloted via Gondwanaland. Of the theropods two genera are peculiar to South America and the third is Megalosaurus, also reported from Australia, India, Germany, England, etcetera; but this genus is based on fragmentary material and I am by no means convinced of the correctness of the assignment. Of the sauropods, two again are peculiar to South America and the third is Titanosaurus of Africa, India, England, and France. The genus is based on two caudals from India, and the figures and description make the South American fragments fully as close to some of the North American sauropods. At this time North America had large numbers of both Theropoda and Sauropoda similar to the South American forms and the path was open.

In North America we have some of the earliest reptiles, and it is of interest to take such a sketch classification as Watson's[7] and consider their distribution. Cotylosauria occur in the Upper Coal Measures and

[5] Bull. 103, U. S. National Museum, 1919, p. 611.
[6] Am. Jour. Sci., vol. 29, 1910, p. 1.
[7] Proc. Zool. Soc. London, 1917, p. 167.

Permian of North America and the Middle and Upper Permian of Scotland and Africa. Anomodontia are scattered through North America, Europe, and Africa. Edaphosaurus is North American and European. Dicynodontia are African, Scottish, and North American. There is nothing to indicate that Africa was isolated, and the forms seemed to have moved from Africa to Europe to America, or in reverse direction, easily throughout the Permian.

Eigenmann[8] has used the fresh-water fishes in an extensive argument for Gondwanaland. After cataloguing all the fishes of South America and showing that some have come from North America, some from the salt water, he lists six families, and from maps of their present distribution develops an argument to show that before the Tertiary, and not later than the end of the Cretaceous, there must have been a land connection between Africa and South America. The families are Lepidosirenidæ, Osteoglossidæ, Siluridæ, Pœcilidæ, Cichilidæ, and Characidæ. Of Pœcilidæ he remarks: "Marine, brackish and fresh water—a connection with Africa would be convenient." Of Siluridæ: The Tachisurinæ are marine, and the continental forms could have been derived from this group, as could also those of Africa. This leaves four families. The Lepidosirenidæ are certainly relics of an ancient group, formerly living in abundance in both Europe and North America. The Osteoglossidæ are also a fairly old family, and Dapedoglossus of the Eocene Green River beds shows that the family was in North America at least that early. Cichilidæ also were represented by Priscacas in the Green River beds and by Odonteus in the Monta Bolca of Europe. These three families, then, I would not feel needed an Africo-South American land connection. And this leaves only the Characidæ, a group of some 400 minnows and carp-like forms. None of the family is known fossil. It seems to me the argument from fresh-water fishes is not compelling. All that is needed is to find that this last family contains or contained some form which could stand salt water. The Galaxidæ of Australia, South Africa, and South America used also to be used for this argument, but it has been shown that some of the members of the family enter salt water readily. There are two fossil fish faunas in South America—an Eocene one from Algoas, Brazil, which is dominantly made up of genera very close to the North American Green River forms, and a slightly older fauna, also from Brazil, in which the genera also are closest to North American types.

Among the arguments based on invertebrates, that on the non-marine mollusca is the best, and it is summarized by Pillsbury in the report of the Princeton Patagonian expeditions. An interesting map of the paths of migration of land snails shows one from North to South America (17

[8] Princeton expeditions to Patagonia, vol. 3, 1905-11, p. 310.

families entering by this route), one from Africa to South America—that is, via Gondwanaland (13 families traveling this route)—and a third from Patagonia to Australia and New Zealand. Of the forms which came via Gondwanaland some seem to have originated in Asia, others in Europe, and still others in Africa. While this is one of the best arguments for the land connection, when dealing with land snails I can not get out of my mind the remarkable records of the long periods snails have been able to withdraw into their shells and go without food or water. The lines of migration correspond surprisingly well with the directions followed by the oceanic currents which touch the South American coast, and this group, above all others, lends itself to distribution by floating rafts or even driftwood.

Perhaps the oldest argument for Gondwanaland is based on the Glossopteris flora, a group of Pteridosperms characterized by the fronds being simple and undissected, like those of the walking fern. Not all of the flora, however, has simple fronds, but some are at least once pinnate like Neuropteris or our common polypody. This flora, in its full development, appears in South America in the Permian and just overlying the glacial deposits. Soon, however—that is, in the higher beds—the flora alters its character by the reappearance of fronds of more dissected type, like Pecopteris and Neuropteris. This same sequence of events is also found in India, Africa, and Australia. The genera typical of the Glossopteris flora are generally placed among the pteridosperms on account of the lack of any spore fronds and, in case of Glossopteris, because of finding seed cases. Such a genus as Neuropteris seems to be the nearest northern relative.

To my mind, the most pertinent question in regard to these southern floras is whether the cold climate of the glaciation would cause the shape of the frond to be altered, say from a once pinnate type to an undissected type. My feeling in the matter is strongly influenced by having recently looked over a large collection of ferns of the genus Polypodium. My idea of what a polypody was like was obtained from seeing them in the woods of northern United States, and I got the idea of a frond much like Neuropteris. I found, however, that had I lived in China I should have had a picture of polypodies with simple undissected fronds (glossopteris-like), for there all were of this sort. Had I lived in the West Indies I should have thought of them as either simple or once pinnate. The same would be true of India or Hawaii, but had I gotten my idea in Europe I should have thought of the fronds as once pinnate or even finely dissected. The fronds of this one genus range from finely dissected, through the type familiar to us all, to forms as simple as any Glossopteris. If this genus of ferns varies so in the shape of its fronds (the reason for which I do not

know), should we be surprised if the same sort of thing was true in the Permian, especially when we know of the great change in climate during that period. My feeling, then, is that until it is demonstrated that the fruiting of Glossopteris and similar genera is really distinct from that of other seed ferns, it is just as well not to postulate a great continental connection joining all the lands of the southern hemisphere, based on this group at least.

CONCLUSION: MAMMALS THE FIRST VERTEBRATES FULLY ADAPTED TO LAND LIFE, AND FAUNAS OF SOUTH AMERICA CAME FROM NORTH AMERICA

In concluding, might I emphasize the statement made early in the paper, that among vertebrates it is not until we come to the mammals that we have a great class which has fully adapted itself to living on land plants. In this we see the reason why this group so suddenly expanded into luxuriant and diverse adaptations. For the first time food supplies were well-nigh unlimited, and animals were not going back through a series of preying on each other to the water plants for their ultimate source of food; but, having cut out an indefinite number of intermediaries, each such intermediary, taking some 90 per cent toll in passing the food along, went directly to the land plants so abundant about them for their food.

Among the mammals, it is the herbivores which have progressed in the most manifold and astonishing ways, and this is not to be wondered at; for they have the direct access to the world of new plants which arose as insect pollination came in. They are the ones which lived in great numbers, bizarre forms, and bewildering changes.

Then I have reviewed the evidence on which some of the most typical arguments of the land connection between Africa and South America are founded. In each great group there is in South America some form or forms for which a land connection would be convenient, but in no group is the number for which such a bridge is postulated large, and for none of them is the demand overwhelming. In all cases it is difficult to explain why the migrations did not go out as well as into South America. As we should expect, there are some forms in each group the past history of which we do not know. The better we know the history, the less demand there is for such a bridge. To me it seems that the bridge in each case was called into being for the purpose of making the discussion of a group complete, when the wise method would have been to mark the group and wait for further knowledge. Perhaps I can say these things, for I postulated this land bridge, and now wish I had left the discussion a paragraph shorter.

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GROUNDWORK OF THE EARTH'S DIASTROPHISM[1]

BY T. C. CHAMBERLIN

(*Read before the Society December 29, 1920*)

CONTENTS

INTRODUCTION

Recent studies have been fruitful in bringing to light new evidences of diastrophism. The older terranes have been found to be more and more intricately deformed, as inquiry proceeds. The later terranes have disclosed overthrusts of unexpected extent and frequency. Troughs of graben type have been found to form chains of almost continental length. The recognition of unconformities has been multiplying to an embarrassing degree. Moreover, as inquiry passes from local and regional fields to the greater features of the earth, the continents and the oceanic basins it discloses evidences of a profound order of diastrophism whose significance has been only meagerly recognized in the past. In the light of these revelations, it is important to workers in this difficult field to know whether

[1] Manuscript received by the Secretary of the Society February 3, 1921.

sufficient resources of diastrophism support all the types of interpretation that are currently offered for acceptance. If the dynamic resources that form the groundwork of any type of interpretation are obviously insufficient to actuate the great diastrophisms implied by direct evidence, the deficiency should be recognized and this mode of interpretation placed on the shelf. It is the purpose of this paper to discuss the fundamental sources from which energy available for actuating diastrophism may arise. This necessarily leads back to the genesis of the earth, for in the mode of its formation there should be found the energies it later displayed.

Two basal Hypotheses

From the dynamic point of view, two types of genetic hypotheses practically cover the whole field: the one, gaseous or quasi-gaseous; the other, orbital. The two rest on distinctly different systems of dynamics, and they inherited unequal measures of energy; their potential resources of diastrophism were thus diverse from the start. In addition to this, and even more important, their modes of evolution led at once to divergencies in the degrees of conservation or of dissipation of their inherited energies. Accepting the common view that the earth was once extensively deployed, it is quite clear that its material carried sufficient energy to actuate any diastrophism that has been disclosed or is likely to be discovered in the earth, whether its substance was distributed gaseously or orbitally. An orbital deployment must have carried much the greater potentialities, but both should have carried sufficient energy, if well conserved and brought into service. In this sense, either of the two hypotheses may be regarded as competent potentially. *The vital difference lies in the extent to which the two modes of descent conserved their original energies, or wasted them before the time for diastrophism came.*

The collapsing Type

Gaseous organization is an ideal type of a failing structure. If matter is removed from any point within a gaseous mass, the whole collapses on the vacancy, because the support of the mass depends on the repellancy of the molecules at all points within it. So, also, whensoever radiation of heat or any other influence is brought to bear on any part of a gaseous body, or on the whole, so that its energy is reduced, the body proportionately collapses and reorganizes itself to fit the new status of its energy In so far, then, as there was opportunity for the radiation of heat or for other losses of energy, during the formative history of a gaseous earth, it promptly collapsed to a smaller spheroid of similar form, and thus

much of its potential energy was dissipated without leaving any diastrophic record, in the accepted sense of the term.

The non-collapsing Type

On the other hand, if the molecules that were to form the earth were moving in individual orbits about their controlling center, they were essentially independent of one another; they had moving forces of their own; they were self-supporting. If any molecule was cooled or removed, it made little difference to the rest. They kept on in their predetermined paths. And so an orbital nebula is not directly collapsible, in the sense that a gaseous nebula is. The individual molecules of an orbital nebula are likely to be gathered in ultimately, but the process is much more indirect. The time required is much longer; a larger measure of energy is likely to be conserved. A gaseous organization is so constituted as to *expedite* the loss of its energy and hasten the collapse of its mass; an orbital organization is singularly well suited to conserve its energy and to *delay* concentration.

The wasteful Type

Under the traditional concept of the gaseous origin of the earth, not only was its energy radiated rapidly away, with collapse closely following, but the energy that remained was largely engaged in maintaining fluidity, for the prime effect of the collapse was an accelerated conversion of potential energy into additional heat (Lane's law). The earth mass was thus all gathered in before the concentrating process could record itself as diastrophism because of the fluid state. (I use the term diastrophism to denote any distortion that keeps a record of itself in the solid state. Concentration, of course, takes place in a liquid body, but it retains no record of any distortion of its structure that may arise incidentally, for a new and symmetrical structure is at once formed in accordance with hydrostatic laws.) No one, I think, has ever assigned any diastrophism to the earth so long as it remained in a fluid state; obviously deformation was only assignable after the whole earth mass had been assembled and had cooled sufficiently to become crusted over. In the meantime the earth-matter was drawn toward its center of gravity as far as its molecular activity would permit, and a corresponding portion of its potential energy was converted into heat. A maximum temperature was thus preserved which greatly facilitated the loss of energy by radiation, especially as this follows the law of the fourth power. According to Lane's law, the temperature tended to rise and the rate of radiation to increase so

long as the gaseous condition remained. While in this active fluid state the possibilities of chemical combination of the earth substances should have exhausted themselves so far as temperature permitted. So, also, should the physical adjustments of the matter. According to the old masters, whose logic was admirable, the heaviest substances should have gathered at the center, the less heavy next, and so on in order, the lightest forming the outer layer. Thus the earth should have taken on almost perfect symmetry, and at the close of the assembling process it should have been in perfect isostatic equilibrium, both vertically and horizontally.

Thus we see that, to a maximum degree, the potential energies represented in the original deployed state should have been converted into fugitive forms of energy and have been dispersed *before any diastrophic record could be made.* There was little possibility of shrinkage left except the meager amount that could arise from further cooling.

The conservative Type

On the other hand, if we neglect for the time being so much of the central part of the earth as is supposed to have been formed from the earth nucleus, as defined in the preceding article, and assume that the outer and much larger part was built up of planetesimals or planetesimal dust, in a relatively cool and solid state, an earth of very different potential resources of diastrophism would arise. To fully realize this, it should be noted that after the earth had reached the mass of Mars it should have been able to hold a notable atmosphere. All the planetesimals that made up the later growth must have plunged through this atmosphere after the fashion of meteorites on their way to the earth. Their velocities were thereby checked and their substance more or less converted into dust.[2]

The outer mass of the earth, built up thus at random by the infall of mixed clastic material, should have been highly porous and should have retained almost a maximum of susceptibility of compression in a solid state. Moreover, the distribution of the infalling matter by the atmosphere and hydrosphere should have been irregular, so that compression must have worked on uneven textures as well as varying substances, and hence should have produced distortion. As this was the distortion of solid matter, it should have retained a record of the action.

The mass as first built up should have been heterogeneous in chemical composition and almost totally devoid of adjustment in respect to density

[2] For a discussion of the size, rate of infall, and physical condition of planetesimals, see Article xiii. Diastrophism and the formative processes. Jour. of Geol., vol. xxviii. (1920), pp. 665-701.

and other physical properties, and so these important sources of reorganization involving more or less diastrophism should have been retained almost intact. More or less of air and water should have been entrapped in the growing clastic mass, and these should have helped to fit the mixture for eruptive action later, when the conditions of vulcanism arose.

The long Series of successive Deformations

The potential resources of diastrophism entrapped in the growing earth should have begun to take on the early phases of actual diastrophism as soon as appreciable pressure was brought to bear on the loose material by the weight of added layers, and this initial diastrophism should have been followed at intervals by a long series of like partial self-compressive actions brought successively into function as the mass grew. These would give rise to various forms of cumulative distortion, local and general. It is immaterial to the general purposes of this discussion just how the deformations took place, beyond the basal fact that it was the distortion of solid matter. Probably the whole series of distortional methods were involved. Probably even partial liquefaction, as it arose here and there, gradually and selectively, gave rise to new distributions of stresses and led on to diastrophism of the enveloping and interstitial solid matter. It is a vital part of the doctrine here urged that the growing globe was kneaded by the rhythmical action of imposed forces, and squeezed the interstitial fluent matter out into the colder zone or quite to the surface. This action would, in its own fashion, contribute to new differentiations and new distortions of the associated solid parts, and so be a cooperating factor in diastrophism.

The early and persistent Development of Surface Differentiation

One of the early effects of deformation thus instituted should have been the development of surface reliefs of the same general types as those that accident the surface today. These surface reliefs must have had their inevitable effects on the currents of the atmosphere and of the hydrosphere, as these grew up with the growing earth. These currents in their turn should have reacted on the surface features much as they do now. The whole complex of surficial agencies should thus have begun their intricate and mutually reactional work. The later incoming matter must, then, have been more and more differentiated by these growing surficial agencies. They thus continued to cooperate with the volcanic and diastrophic actions that spring from the deeper horizons, so long as growth continued to be effective. With little doubt, a maximum of differentia-

tion was reached at a certain stage, after which there set in a long effort to reach a better balanced distribution, a movement still in progress. Thus, in the growing stages, each partial deformation led on to increased differentiation of the incoming matter, and so laid the foundation for still further diastrophism when these effects turned into causes. In a certain sense, the complex process was cumulative, even though the resulting diastrophism, taken by itself, tended toward the equation of stresses and a better balancing of inequalities.

The persistent Effects of the deeper Diastrophism

The earlier deformations were, of course, buried deeper and deeper and made more and more inaccessible as growth went on. It is easy to jump to the conclusion that they thus became inconsequential, so far as the outer diastrophism was concerned; but a little consideration will show that deformation in the depths, however buried, continued to be a potent factor in the diastrophism above, and that of later dates as well. All the earlier distortions gave warped foundations for all later compressions. Thus, in a sense, they transmitted their deformities and weaknesses to the terranes built on them. Besides this, and more important, *the matter in the depths partook anew in every recurrent stage of self-compression.* This was logically inevitable unless the substance reached a state of incompressibility, and this notion has become untenable since the compressible nature of even the atoms has been disclosed. But we need not fall back on this, for a comparison of the density of the earth with its neighbors clearly implies that central compression continued to be effective so long as the planet grew.[3] After a careful study of the case, it seems safe to say that the high densities of the interior were not original, nor were they attained at any single stage, but rather by renewed stages of self-compression which affected each inner layer in its due proportion. This is clearly implied by the law of increasing density, which is not only theoretically sound, but is supported by the convergent testimony of several lines of concrete evidence, in addition to the comparison already cited.

The Penetration of this basal Diastrophism

The considerations just sketched may almost serve as a discussion of the depth of penetration of all such diastrophism as sprang from increase of mass—that is, the basal diastrophism that especially prevailed during the formative stages of the earth.

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[3] Diastrophism and the formative processes. X. The order of magnitude of the shrinkage of the earth deduced from Mars, Venus, and the Moon. Jour. of Geol., vol. xxviii (1920), pp. 1-17.

If the earth, as it grew up, had been perfectly homogeneous, layer by layer, as in the supposed fluidal earth, the whole effect of increased mass might have been merely a uniform self-compression; but since the texture and composition of the earth was very heterogeneous in a minute sense and became regionally diversified in a large sense, by reason of the external agencies that affected its growth, it was inevitable that distortion should arise not only whenever, but wherever, self-compression took place. It is thus a firm inference that diastrophism in some form permeated, in a general sense, the whole of the self-compressing body, certainly the whole of that part which was built of planetesimals. The concept of merely surfical diastrophism, in response to general stresses in a body having such a genesis, seems to be altogether untenable. Of course, there were local distortions of all sorts, surficial as well as otherwise.

THE TOTAL VALUE OF THE SELF-COMPRESSION

I have recently endeavored to determine the total amount of self-compression which the earth suffered in the course of its history by means of a comparison of its density, mass, and volume with the densities, masses, and volumes of the planetary bodies nearest to it and most like it in their conditions of genesis, namely, the next inner planet, Venus; the next outer planet, Mars, and the earth's own satellite.[4] The method consisted of building up the moon with moon-stuff, at the moon's density, until its mass equaled that of the earth, when its dimensions and volume were computed, after which it was theoretically shrunk to the density of the earth and the amount of self-compression determined. Though not the actual process of formation, this is believed to fairly represent the degree of self-compression which would take place in a growing body under terrestrial conditions between a stage represented by the moon and a stage represented by the full-grown earth. So, in like manner, Mars was built up of Mars-stuff at Martian density and the self-compression between a Mars-stage and the mature earth-stage computed. So likewise of Venus. The results were concordant in a very suggestive and satisfactory way and were surprisingly large. Between the moon-stage and the earth-stage, the radial contraction was found to be 725 miles, the equivalent of 4,555 miles contraction of the circumference. The shrinkage between the Mars-stage and the earth-stage came out 618 miles radial shortening; that between the Venus-stage and the earth-stage, 177 miles. By a comparison of these results with one another, there came out the further very important conclusion that the self-compression became pro-

[4] Diastrophism and the formative processes. X. The order of magnitude of the shrinkage of the earth deduced from Mars, Venus, and the Moon. Jour. of Geol., vol. xxviii (1920), pp. 1-17.

gressively *greater per unit mass of increase* during the later stages. This bears on the last two subjects discussed, in that it clearly implies *progressive compression of the inner parts.* This conclusion is supported by cogent theoretical considerations. A similar comparison with the great outer planets is not admissible, for their constitution, their intimate history, and their dynamics are distinctly different. They appear now to be largely gaseous and to have been gaseous from the outset. Hence they never underwent the sifting of solar material that was necessary to give the stony and metallic substances that make up the main mass of the solid terrestrial planets.[5] The giant planets were thus evolved under the sole control of gaseous dynamics, and their material differs radically in proportions from that of the small solid planets.

An elaborate inquiry was made to see if any part of the great self-compression indicated by the comparison might be explained reasonably by supposing that the larger bodies had a higher content of inherently heavier matter, but the evidence was found to favor precisely the opposite view. Any consistent mode of genesis makes it almost certain that the larger bodies contain relatively more *light* material than the smaller bodies. It appears, then, that the self-compression of the earth was not only large relative to its neighbors, but that it became increasingly large as the earth-mass grew, and hence that the interior participated in the self-condensing process throughout all stages.

The Cause of the basal Diastrophism

The fundamental source of this great self-compression, and of the diastrophism that necessarily accompanied it because of the differentiated and solid state of the earth material, has been definitely implied in the statements already made and needs to be explicitly stated here merely for emphasis.[6] The self-gravity of the assembling mass converted its own potential energy of position into the actuating energy of diastrophism. This potential energy became available for diastrophism simply because it had been conserved in a high degree by the slow orbital process by which the earth material had been assembled. Secondary causes of diastrophism, of course, cooperated with this basal cause at all stages. During the formative stages the basal cause of diastrophism was probably more dominant relatively than in the later stages. In these, various minor causes seem to have had a higher proportionate value, but in all stages, I think, they are to be regarded as incidental rather than fundamental, at least in the main.

[5] Diastrophism and the formative processes. XII. The physical phases of the planetary nuclei during their formative stages. Jour. of Geol., vol. xxviii (1920), pp. 473-504.

It will help to clarify thought on the subject if we distinguish between the leading part played by heat as the chief *opponent* of shrinkage in a gaseo-molten earth and the secondary part it plays in a planetesimal earth as merely the *product* of compression. In a gaseo-molten earth heat is the main agent that stands in the way of further immediate collapse; it must be dissipated before shrinkage will go further. The old masters were, therefore, quite logical in regarding cooling as the chief prerequisite to shrinkage and deformation; hence cooling seemed to be the chief cause, whereas it was merely the removal of the hindering agency. But, in a body built up of heterogeneous clastic matter at relatively low temperatures, it was at first the solid form of the particles that stood in the way of their collapse; later it was the lack of the most dense chemical combination and physical organization that stood in the way. Heat was thus only one of a group of restraining agencies; it is not even the leading one in the order of action. The polarized forces of the solid state had to be overcome and heat *produced* by compression before it came into action to aid in restraining further compression. This, of course, applies to the heat mechanically produced rather than that which may arise from chemical action of radioactivity. When heat is thus produced mechanically it becomes a cooperating factor of notable importance; it may come to be a leading one, or even the chief one. But, normally, as the heat rises, some part of it is likely to be consumed in endothermal reactions, some in liquefaction, some in crystalline organization, and some in mineralogical and other forms of physical reorganization. In so far as any part of the substances engaged in these complex processes takes a mobile form, gravitative pressure, aided by tidal, nutational, rotational, and other forces which were more or less constantly or rhythmically working concurrently with it, tended to force the mobilized products into higher and cooler zones. They thus mechanically disposed of that part of the heat which produced weakness in the interior, and in that way helped to preserve its rigidity. There is evidence that this restrained the interior action to the limit of insipient liquefaction on the borders of the solid state. In so far as the heat arose from radioactivity, the source is likely to be carried out with its products. A combination of this sort should naturally work toward an equilibrium status between the processes that tended in opposite directions, and this equilibrium status should have for its boundary line the fusion-solution curve. This automatically separated the matter that was rigid enough to hold its place and do its part in maintaining the rigidity of the earth, and the weak yielding part that had to go practically as fast as it arose. In the nature of the case, the equilibrium status—and its determinant on the liquid side, the fusion-

solution curve—was accommodated at all depths to the conditions imposed by pressure, by the constitution of the material, and by other properties. The critical temperature, the solution-fusion temperature, rose as depth increased, but the rate of rise was dependent on too many unknown factors to permit a trustworthy determination, either at present or in the past. The essential point here is that the part which heat played in the complex action was that of a *product* rather than a *primary determinant*. The high rigidity of the earth, now so well authenticated, seems to point definitely to some such automatic mechanism as this. So equally do the driblets of liquefied matter that have been forced to the surface, or to the cool surficial zone, in all the geologic ages, past and present. The working out of this automatic adjustment by the cooperating processes is to be regarded as the attainment of the past billions of years rather than millions of years.

The Time of the most effective diastrophic Action

Among the strong contrasts between the two views of genesis under comparison are those that relate to the time when the chief diastrophic events took place. If the earth was at first a globe of gas, it collapsed as fast as the radiation of its excess of heat permitted. The time consumed in the process was relatively short, for radiation takes place in proportion to the fourth power of the temperature, and the temperature in this case was necessarily high, according to Lane's law. If, on the other hand, the earth was formed by the ingathering of planetesimals, the process followed the laws of orbital dynamics and the formative process was very much slower. It may have taken three or four billion years. In this long period of gradual upbuilding, the graded adjustments just described should have had time to work out their mutual adaptations.

In another respect, also, the contrast was striking. In the traditional gaseo-liquid earth, diastrophism did not start until after the formative process had ceased and encrusting had begun. In the planetesimal earth, the diastrophism began with the earliest accessions and *ran progressively through all the formative stages,* and through all later time. It apparently grew in effectiveness during the main assembling of material, but it appears to have declined when the accessions fell to a relatively ineffectual rate. The most effective diastrophism thus fell *within the formative eons*. The sum total of diastrophism in the whole earth body was thus greatest during the formative eons. It is probable that during any large fraction of the formative ages greater diastrophism took place, even in the surficial shell, than during any of the later periods of equal length, though this can not, perhaps, be affirmed with the same confidence, for it

involves the distribution of diastrophic effects which depends on other considerations than those under study here. The observational evidence respecting the Archean Era, whose terranes are closest of kin to those of the formative stages, seems to support the view that the surficial diastrophism was then greater than during any period of equal length in later time.

BEARINGS OF THE PLANETESIMAL VIEW ON VULCANISM

Under the planetesimal view, vulcanism, as recorded in the geologic ages, arose chiefly from the partial selective liquefaction of eutectic materials as they happened to be in contact here and there in the body of the earth. The squeezing of this mobilized material to or toward the surface by the differential pressures engendered within the earth-body, including the graded stresses, more intense below than above, imposed by outside bodies, was the main extrusive factor of the case. Vulcanism is thus in itself little short of a phase of diastrophism. The heterogeneity of the earth-substance, the inequalities of its distribution, and the prevalence of greater stresses below than above combined to promote both processes and make them helpful companions in action. The distortions of the deformative process are the natural counterparts of the partial mobilizations and displacements of the volcanic process.

In a gaseo-molten earth, all of whose material passed gradually from very high to much lower temperatures, while the mass was stirred by convection at all stages, there should have been developed and brought to the surface all the gaseous material in the earth-substance which high heat could set free. When these hot gases entered the hot atmosphere their molecular velocities should have been at a maximum, and the rate and the extent of their escape from the atmosphere should have exceeded that of any later time. When the long boiling process ceased and the encrusting of the liquid sphere began, there should have been left in the mass a minimum of gaseous material. Only that small measure which might be held there by the partial pressure of like gases in the atmosphere would be assignable under these conditions. The earth-body should then have been scantily supplied with explosive volcanic gases. It would seem, therefore, that an earth-body formed in this way should be unsuited to give rise to such a degree of gaseous vulcanism as is actually manifested. Just as a once molten earth must have exhausted its main resources of diastrophism before a record of diastrophism could be made, so it must have exhausted in its hot youth essentially all its resources of explosive vulcanism before a solid environment was provided to give effect to its explosive possibilities.

In the case of the moon, the logic is even more cogent, for even in its present cold full-grown state its gravity is insufficient to hold an appreciable atmosphere. Certainly, then, in its earlier and hotter stages, if it were once molten, *all* its volcanic gases should have escaped as fast as they were set free, and it should have cooled into a solid, gasless mass. The highly explosive vulcanism of the moon implied by the special features of its present pitted surface and the long lines of debris that radiate from some of its craters, irrespective of the reliefs of the surface, find ready cause under the alternative view, because it supposes that gaseous and gas-forming materials were entrapped during the planetesimal growth. This entrapped material would become an ample source of explosive vulcanism at a later stage, when internal conditions, like those previously sketched in connection with the earth, brought into play their solvent and gas-freeing activities, while differential pressure forced the gases and other mobile matter to the surface. The fragmental state of the outer matter in the absence of the cementing effect of a hydrosphere should give peculiar effect to the explosive action.

Bearings of this View on igneous Petrology

The prevailing view of magmas, when regarded as inheritances from a once molten earth, usually makes them either residues of the original molten mass or else re-solutions, *en masse,* of rock previously solidified. In either case the solidifying process is usually interpreted as involving a differentiation into a series of derivatives which separate more or less successively from the original magma. Magmatic *differentiation* thus becomes the essence of igneous petrology. Its problems become essentially questions of *descent* from an assumed primitive, or quasi-primitive, magma. In the field, the critical issue is to find all the derivatives required to make up, quantitatively and qualitatively, a consistent primitive, or quasi-primitive, magma. The embarrassments are many and formidable.

On the other hand, if magmas consist merely of partial solutions of heterogeneous mixtures, such as would naturally be formed by a multitude of small bodies of different natures falling in at random, they would quite certainly become highly diversified in the making. The primary problem would then lie in the *generation* of the magmas; in the *ascent* of magmas rather than their *descent.* While differentiation in the process of solidification would still remain a factor, it would be a secondary matter, in the sense that it was necessarily conditioned by the previous generative process. The inquiry in the field, in this case, should start with the evidence as to what petrological species and varieties are actually present.

and thence seek the probable mode of genesis where the possibilities are large and the embarrassments few. Each particular case presents purely an *a posteriori* problem of its own. It is wholly unembarrassed by any requirement that its factors shall sum up into a speculative primitive magma.

Bearings on the Problem of Isostasy

A liquid earth should be an ideal example of perfect isostasy in the highest sense—that is, isostasy in perfect *horizontal* as well as vertical adjustment. The earth's crust, as it began to form, should have inherited this quality in full perfection. Such distortions as later arose in the crust from cooling and shrinking were the beginning of a long series of actions that were destructive of this perfect isostasy. Diastrophism is thus made to function at the outset as an antagonist of isostasy. But its normal function, as we find it in action today, is tributary to isostasy. The surface forces of erosion, solution, transportation, and deposition, that must have set in as soon as the deformation of the crust exposed it to subaerial agencies, tended to counteract the effects of the first deformations and thus to reduce the deviation from the originally perfect isostasy. The interplay of diastrophism and the surface agencies tends in general, but not in all particular cases, toward the equalization of weight among the earth columns—that is, toward isostasy. If diastrophism produces inequalities at variance with isostasy, the surficial agencies and creep tend to restore isostasy; if diastrophism produces inequalities in the interest of isostasy, the surface agencies tend to smooth out the inequalities in disregard of isostasy. The two sets of agencies tend to hold one another in check. Starting with perfect isostasy and with little more than the meager effects of cooling to actuate diastrophism, we should not expect these mutually checking processes to permit inequalities to get far from the original isostataic state. On the assumption of a once molten earth, the first and greatest problem of isostasy is then to find an adequate and consistent explanation of the profound differences of density that are revealed by present evidence. Many years ago, when I still accepted the molten theory, I worked industriously on this problem of the differentiation of what must once have been very homogeneous material theoretically, but I never reached a solution that met the full requirements. The first few steps seemed easy and promising, but very soon the counteracting processes rose in efficiency and tended to destroy the gain that had been made. The combination of processes seemed to confine the extent of their differentiating effects to limits much short of the effects actually in evidence. I am not aware that any one has had better success.

On the other hand, the planetesimal view brings into play a group of effective processes which tended to cumulative differentiation of the material of the earth from the earliest stage of accession throughout the whole period of growth, though these were also antagonized by some counteracting agencies; but the limit in this case was very much broader. As a result, the full-grown earth inherited profound differentiations of material. These had a broad regional distribution correlated with the currents of the atmosphere and hydrosphere as well as the main lines of early diastrophism. From these fundamental differentiating agencies there arose segments of lighter and heavier material of continental and oceanic dimensions. These diversities are held to be the specific ancestors of those that now manifest themselves in the great reliefs of the earth. It is the prodigious task of surface agencies and of diastrophism, working together, to bring about, in the course of coming ages, a closer equation between these segments of lighter and heavier matter. This will require a vast lapse of time; but we have no wish to hasten its completion. The perpetuation of land life hangs on the extent of the delay in its accomplishment.

Probably one of the greatest contributions of isostasy, when its values shall be fully realized, will be its testimony to the significance of those wide and deep inequalities of substance which make possible the great reliefs of the present earth's surface.

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THE GREATER EARTH [1]

BY T. C. CHAMBERLIN

(Read before the Society December 29, 1920)

CONTENTS

THE MATERIAL EARTH AND THE DYNAMIC EARTH

The earth, like ourselves, has a material organization and a dynamic organization. In the early history of our race we gave chief attention to physical affairs, but the time came at length when we began to gather together, as we do here today, to exchange the products of our dynamic personalities. I think you will agree that the latter is the greater phase of man. So the physical aspects of the earth have received chief attention thus far; but the time has come, I think, when the study of the earth should turn more largely to the dynamic. Very naturally the outer and more intangible phases of the dynamic earth have received scant attention, either from geologists, concerned primarily with the earth-body itself, or from astronomers, concerned primarily with the more fascinating displays of the distant heavens. The inner, invisible heavens, into which the outer reaches of the dynamic earth penetrate, have lain neglected as the borderland between two more tangible domains—as a sort of "turn-row" between two better cultivated fields of absorbing interest.

[1] Manuscript received by the Secretary of the Society February 3, 1921.

Like the broad "turn-rows" between the pioneer farms—with which we of the older school were once so familiar—its cultivation has been left for a later day. It is still largely virgin soil.

It has therefore seemed worth while to assemble in diagrammatic form some of the more salient features of the dynamic earth. In this I am little more than a compiler. I shall do little more than put together what I have picked up here and there during the last twenty-five years and found useful in the study of earth problems. The compilation may serve your convenience, for the items were found scattered through a wide range of literature relating to several different subjects; some, indeed, have not been given a definite literary form at all. These I have drawn out from those who happened to have them, or happened to have the unrelated material from which they might be organized.

It is too familiar to need saying that the gravity of the earth reaches out far beyond its material organization and brings to bear a certain measure of distant influence; it is not so clearly recognized that this rises to certain specific degrees of *dominance* over definite portions of the space around the earth and falls to a merely negligible degree of influence over the space beyond that. Only the *controlling* influences interest us as students of the earth; but these are vital. I shall deal with little beside the gravity prowess of the earth, starting with the earth's gravitative sphere of control. The earth is enveloped by spheres of electrical and magnetic influence, but the present state of our knowledge does not warrant an effort to define these. And then there are many intimate forces—crystalline, colloidal, chemical, cohesive, adhesive, etcetera—which determine the more immediate structures of the earth-body. Of these I shall not speak; I merely wish here to recognize that they are essential in a complete picture of the dynamic earth. The gravitative influence of the earth must stand as its dynamic representative; this is not unfitting, since it appears to be the most important of the outreaching forces.

The Earth's Sphere of gravitative Control

Many years ago Laplace recognized that the earth and similar bodies had special spheres of gravitative influence, and the phrase "spheres of influence" came into use among astronomers as the technical term for this, so far as the subject received attention at all. The phrase is employed in a sense closely like that in use in international affairs; it does not so much designate the form as the degree of influence. The "sphere of influence" of Japan in China is not spherical, nor does the "sphere of influence" of a planet imply that it is spherical, though it is usually spheroidal.

In a complete analysis, the gravitative influence of a planet extends indefinitely outward—at least in Newtonian dynamics—but at a certain point the *dominance* of gravitative influence, in any given sense, passes from the planet to some neighboring body or assemblage of bodies, and so the phrase *"sphere of control"* seems preferable, as it carries its definition on its face. The control is not absolute or unqualified; it is usually subordinate to a higher control. It usually relates only to the *immediate* control over bodies that have like motions, as when larger and smaller masses are moving about the sun in much the same way, the larger controls the immediate movements of the smaller within its sphere of control, though the motions of both are controlled by the sun. This is merely a generalization of Moulton's concrete definition, "the area within which a planet can control a satellite." [2] The relationship is a relative one, and there are some refinements of definition that need not embarrass us here. The special conditions of any particular case must, of course, be recognized in treating it. All that is important here is the essential concept of the sphere of control and a realization of its functions in the life of the body under study.

The sphere of control of the earth is its dynamic domain. It forms the truest and best delimitation of the earth as an organized body and as a subject of study. It is the most distinctive feature of the greater earth. It embraces more than five million times the space occupied by the material earth. But the greater earth is really not so much this outlying invisible part as it is the whole combination, the physical center supplemented by the outreaching dynamic domain. In ultimate analysis, the material and the dynamic portions are, perhaps, only different phases of the same ultimate entity, whatever that may be. At any rate, we know of no way by which the two can be separated in our present state, though we must treat them as more or less distinct. We have come here to exchange the products of our dynamic personalities; but we brought our bodies with us; if we had not, I fear the value of our merely dynamic efforts would have been negligible.

Diagram I is introduced to illustrate the general relations of the sphere of control of the earth to the sun. It is to be understood that the sun's sphere of influence envelops the whole and stretches far beyond the limits of the diagram. On the scale here used, the solid earth is a mere dot; the small circle embracing it is the orbit of the moon, while the sphere of control is outlined by the oval that embraces both these. At the left the sun is represented on the same scale as the earth's sphere of control. The volume of the latter is somewhat more than twice that of the sun. The

[2] The spheres of activity of planets. Popular Astronomy, no. 60, 1899.

distance between these needs to be multiplied 125 times to be in proper proportion.

It is of no little importance in dynamic studies to keep ever in mind that the earth's sphere of control not only revolves within the sphere of control of the sun, but that its position is *deep* within it. The sun's sphere of control extends at least several hundred times as far beyond the earth as the earth is from the sun. Its precise extent has not been determined; indeed, is not determinable at present, from lack of sufficient data respecting competitive attractions outside. I have, however, endeavored to reach an approximate notion of its extent by projecting graphically certain dynamic indications of its extent found in the outer planets. These imply that the radius of the sphere of control of the sun

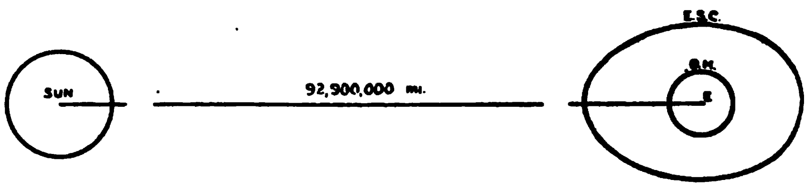

DIAGRAM I

Scale about $\frac{1}{396,800,000,000,000}$

FIGURE 1.—*Diagram illustrating general Relations of Sphere of Control of Earth to Sun*

E., earth; O. M., orbit of moon; E. S. C., earth's sphere of control. Scale of sun and E. S. C. the same; scale of distance between them 1/125. Gegenschein, according to Moulton, lies just outside oval E. S. C. on right.

may be of the order of 700 astronomical units—that is, 700 times the distance of the earth from the sun—but the liability to error in this extrapolation is large. The dynamic earth thus revolves deep within a dynamic sphere much more extensive and much more powerful than itself. Because of this overcontrol, all problems that bring these competitive factors into play must be worked out in the light of this relationship. Even more than this, I find it helpful to picture the whole of cosmic space as stressed by the gravity pulls that make up the spheres of control of all the celestial host, not only considered separately, but in their natural groupings. As all the celestial bodies are in motion, it is necessary to think of these spheres of control as shifting in extent, form, and force as they change their positions relative to one another.

Neither the problem of the earth's genesis nor that of its atmosphere can be discussed trustworthily without due consideration of the stress-environment under which the greater earth had its origin and has had

its being ever since. The sphere of control of the earth-nucleus was a vital factor in the collection of the planetesimals to which the earth's main growth is assigned under the planetesimal hypothesis. A related process is the assigned means by which the essential constitution and measurable uniformity of the earth's atmosphere has been maintained. The latter most easily and concretely illustrates the indispensable importance of the earth's sphere of control in its vital career. According to the kinetic theory of gases, the molecules of the earth's atmosphere are liable to acquire very high velocities by reason of successions of collisions and rebounds whose effects happen to be cumulative. It follows that certain molecules are escaping from the control of the earth at more or less frequent intervals, as also from all other bodies that have effective atmospheres. The critical velocity of escape and the frequency of escape are determined, *not* by the attraction of the earth regarded as a body isolated in space, but by *the relative values* of its attraction and that of its chief competitor, the sun. In neglect of this, it has been common practice to take the parabolic velocity of the earth—that is, the velocity that would carry a molecule to infinity—as "the critical velocity of escape." This prevalent error and others related to it have greatly retarded the general acceptance of the important doctrine of Stoney, that the atmospheres of planets are controlled by the gravities of the planets. It is obvious, however, on the inspection of the diagram, that it is only necessary that a molecule should acquire velocity enough to carry it beyond the limit of the earth's sphere of control, into the sphere of control of the sun, to insure its loss to the earth's atmosphere. It is obvious from a mere inspection of the case, in the light of the kinetic theory of gases, that the earth must be throwing molecules into the sphere of control of the sun all the time, and the sun must be reciprocating in due measure. The interchange naturally tends toward an equilibrium. Whichever ultra-atmosphere becomes the richer, for any reason, throws the more molecules into the one which is the poorer until the two reach a stage of equivalent richness. In this automatic way the control of the atmosphere is assured and the conditions essential to terrestrial life are perpetuated.[3]

Diagram II illustrates the sphere of control of the earth on a larger scale, with the sphere of "*equal*" gravity added. The smaller radius of the earth's sphere of control is about 1,000,000 kilometers (620,000 miles) and its greater radius about 1,500,000 kilometers (930,000 miles). The latter lies in the line joining the sun and earth. The counterglow (*Gegenschein*) lies just outside it, opposite the sun, according to the theory of Moulton. The limit of "equal" gravity between the earth and

[3] The origin of the earth, 1916, pp. 25-27.

the sun is represented by the line E. G., within the orbit of the moon, O. M. At first thought, this position seems quite anomalous, if not absurd. The moon is controlled by the earth, and yet its orbit is represented as lying outside the line marking equal gravity between the sun and earth. The seeming anomaly depends on the relative motion of the bodies concerned. If they were all standing still or were all moving at equal speeds in the same direction, a particle on the line E. G. would be

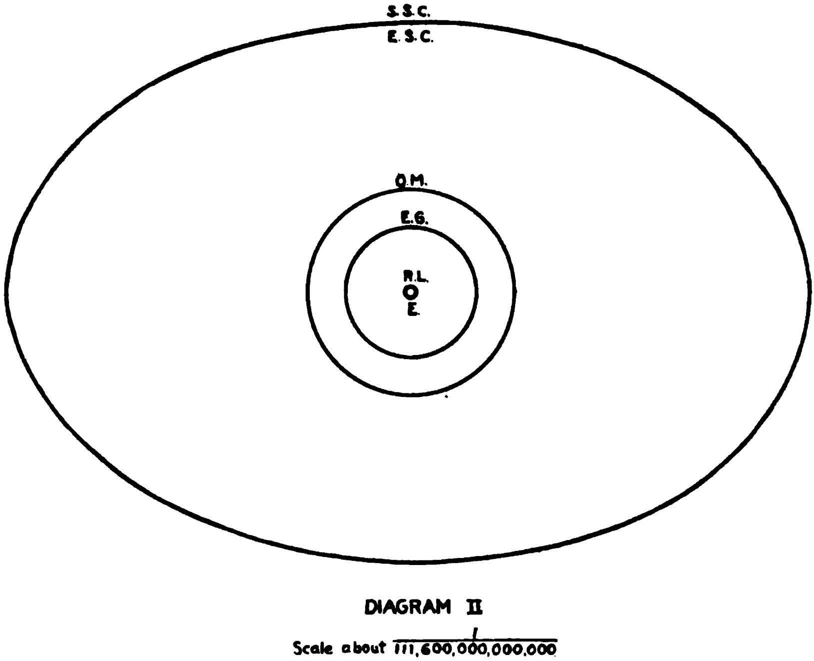

FIGURE 2.—*Diagram illustrating Sphere of Control of Earth on larger Scale*

E., earth; R. L., Roche limit; E. G., limit of equal gravity between earth and sun: O. M., orbit of moon; E. S. C., earth's sphere of control; S. S. C., inner earthward border of sun's sphere of control, which extends outwardly several hundred astronomical units. Shortest radius of earth's sphere of control, 620,000 miles (1,000,000 kilometers); longest, 930,000 miles (1,500,000 kilometers).

attracted equally by the earth and by the sun; all bodies outside E. G. would be drawn most toward the sun. But, as a matter of fact, the earth and the moon are both moving around the sun in very similar orbits, and hence the centrifugal component of their motions neutralizes a considerable part of the attraction of the sun, without appreciably affecting their own mutual attractions. Their mutual attractions are therefore relatively more effective than the sun's attraction for them. This is a case of *relativity,* in the old familiar sense of the term. This seeming anomaly

serves to make more clear just what is meant by sphere of control, as the term is here used—that is, control under the conditions of relative motion of the bodies under consideration. Moulton's concrete definition most

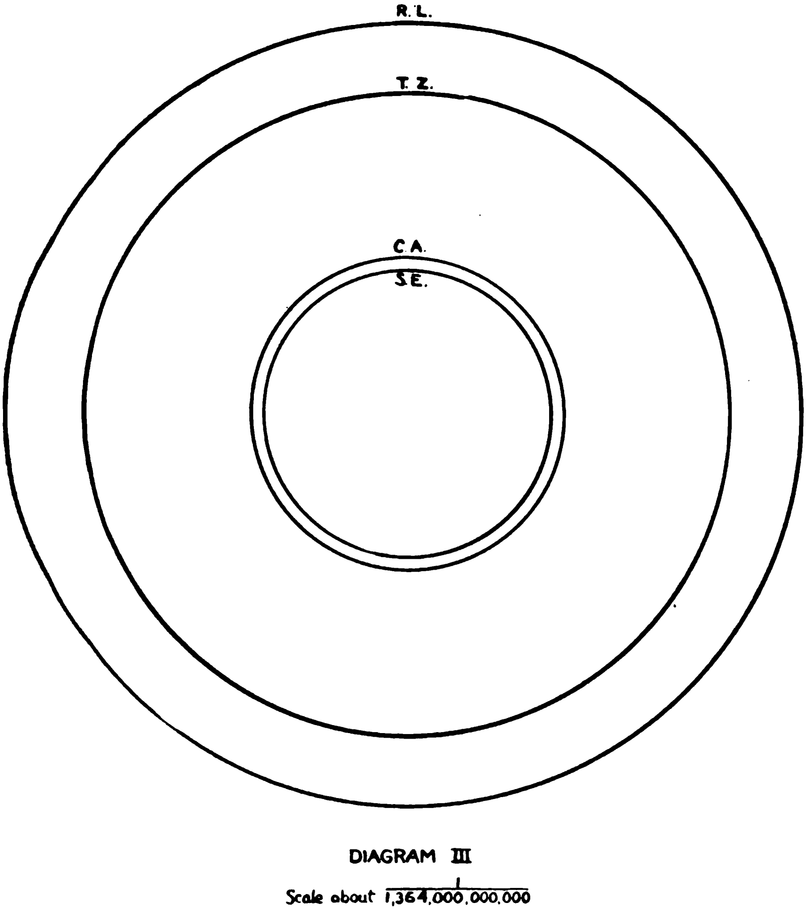

FIGURE 3.—*Diagram visualizing certain dynamic Distinctions much nearer the Earth-body*

For relative scales compare R. L. of Diagram II with R. L. (Roche limit) of Diagram III; T. Z., limit between present tidal zones; C. A., approximate transition zone between the inner collisional atmosphere and the outer ultra-atmospheres, krenal and orbital; S. E., surface of earth.

conveniently fixes in mind the essential conditions, "the space within which a planet may hold a satellite," or the equivalent of this in generalized terms.

The Roche Limit

Diagram III is intended to visualize certain dynamic distinctions much nearer the earth-body. The outer line, R. L., represents the Roche limit of the earth. This is the limit within which the differential attraction of the earth would disrupt a satellite approaching it on an inrunning spiral, under certain specified conditions. This important dynamic feature was disclosed by the mathematical researches of Eduard Roche, of Montpelier, France, more than a half century ago; but it has not received all the recognition it merits. It interposes a bar to certain cosmological evolutions which, in neglect of it, have been rather freely postulated and widely accepted. The specific conditions on which Roche based his computations were rather artificial. The planet and satellite were both assumed to be homogeneous and incompressible and of the same density, while cohesion was neglected. Under these assumptions the limit of disruption was placed at 2.44 times the radius of the planet. When properly modified, the dynamics involved are applicable to a wide range of actual instances. The Roche limit on the diagram is placed at 11,000 miles from the earth's center, following Sir George Darwin. This recognizes a certain measure of concentration of matter toward the center of the earth, but no allowance is made for the elastic factor that is inevitably present because of compression and internal heat. Most compressed hot bodies would obviously tend to explode if their gravity was neutralized in any large measure by the attraction of another body. This expansive factor would probably much more than offset cohesion. If the moon were to approach the earth on an inrunning spiral, I think it would be fragmented by expansion and explosive action much before it reached the assigned Roche limit. The rings of Saturn are possibly made up of the dissevered and scattered residue of one or more satellites drawn within the Roche limit by the growth of Saturn in an early stage of their formation.

Tidal Zones

Inside the Roche limit is another dynamic boundary of some significance. It defines areas within which the tidal reactions of the earth and moon have contrasted effects on the orbit of the moon. Outside the line T. Z. the tidal reaction between the earth and the moon has the effect of driving the moon into a constantly enlarging orbit; on the inside it would draw the moon toward the earth. This critical distinction was recognized by Kelvin and Darwin, and the dividing line has been recomputed by Moulton and Lunn independently. Roundly, for the present rate of rota-

tion, it is 9,000 miles from the center of the earth. This feature adds its own embarrassment to that of the Roche effect in all attempts to work out into specific terms a theory of the origin of the moon by the fission of an earth-moon body. A still more formidable difficulty arises from the determination, by Moulton, that the fission of an earth-moon body, if assigned to progressive rotational changes (such as the passage from an oblate to a prolate spheroid, thence to a pear-shaped body which by progressive constriction divides into two bodies), could only take place by shrinkage to a density far beyond that now attained—indeed, far beyond that rationally assignable under any known conditions. The fission theory appears thus to be entirely untenable in the earth-moon case and in similar cases.[4]

Division between the collisional and ultra Atmospheres of the Earth

The line C. A. marks roughly the zone of transition between the highly collisional state of the earth's atmosphere near the surface and the vaulting state above, described long ago by Johnstone Stoney.[5] This vaulting state, or krenal ultra-atmosphere, in turn passes outwardly into an orbital state, or orbital ultra-atmosphere, as I have elsewhere shown.[6] These transitions are, however, very gradual; there is no definite line of separation. Collisions prevail in lessening frequency throughout the whole sphere of control, but they are only dominant near the earth. The line C. A. is placed at about 300 miles from the surface of the earth merely to represent a horizon at which a large proportion of the free paths of the molecules are great enough to encircle the earth, and so give rise to orbital movements, in contrast to the short, straight, free paths of the molecules in the atmosphere at the earth's surface. The diagram serves also to show how enormously greater is the space occupied by the krenal and orbital ultra-atmospheres than by the collisional atmosphere; but this greater volume is more than offset by the extreme attenuation of the outer atmospheres. In their extremely sparse way, the ultra-atmospheres occupy all the outer space of the earth's sphere of control. Beyond that, and enveloping it, lies the sphere of control of the sun, occupied in like manner by the sun's ultra-atmospheres, as previously noted.

[4] The tidal and other problems. Pub. No. 107, Carnegie Institution of Washington, D. C., 1909, p. 159.
[5] On atmospheres upon planets and satellites. Trans. Roy. Dublin Soc., 1898, p. 305.
[6] The origin of the earth, 1916, pp. 19-27.

AN UPPER TURBULENT ATMOSPHERIC ZONE

In Diagram IV we come closer home to the dynamic features of the earth-body itself. On the way, however, let us take advantage of the

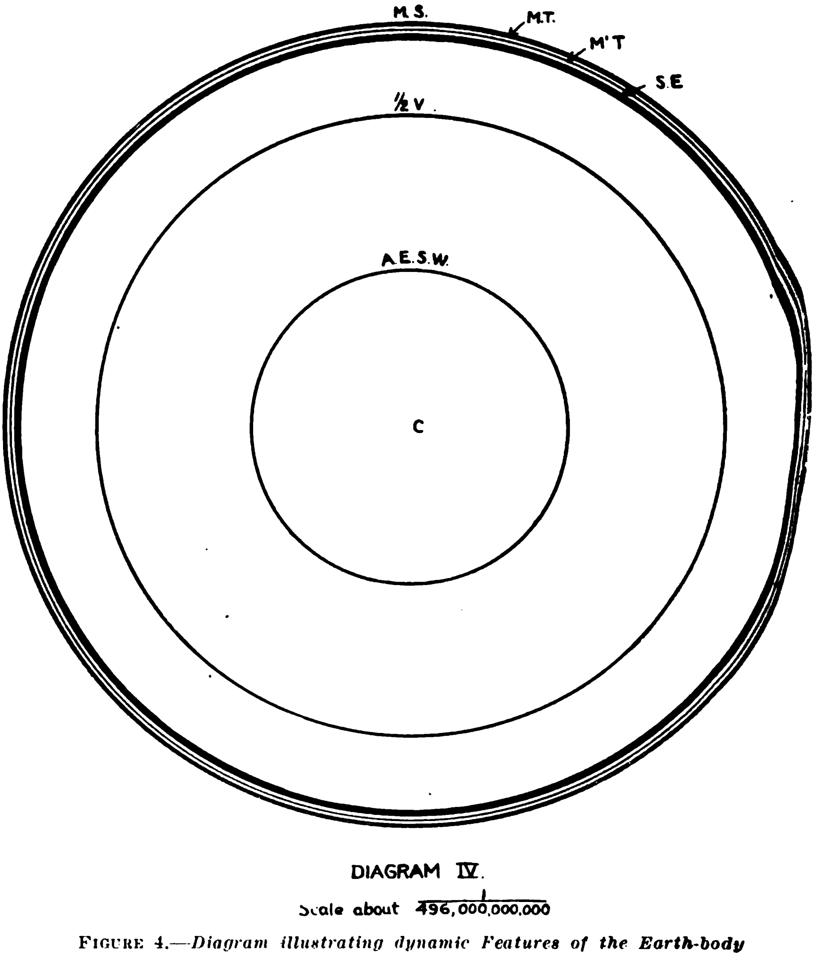

FIGURE 4.—*Diagram illustrating dynamic Features of the Earth-body*

M. S., upper limit of meteor streaks, 80 to 90 miles above surface; M. T. and M'. T'., upper and lower limits of zone of meteor *trains*, 70± to 40± miles; S. E., surface of earth-body; broad black line represents surficial diastrophic zone; 1/2 V. marks division of earth's *volume* into outer and inner halves; A. E. S. W., approximate border of spheroid of anomalous effect on seismic waves; also hypothetical surface of earth core; C., center of earth.

larger scale to visualize a neglected feature of the upper collisional atmosphere. The outer thin line, M. S., represents the upper limit at which

meteors plunging into the atmosphere become visible; it is commonly about 80 or 90 miles above the ground; rarely 100 miles. Below that line are two other thin lines, M. T. and M′. T′., the outer one 70± miles above the ground, the inner one 40± miles. They inclose the zone within which meteorites develop *trains* in addition to streaks. These trains seem to be sheaths of luminous air that diffuse outwardly from their axes. They remain visible for periods ranging up to an hour, and occasionally, but rather rarely, more. These give visibility to the movements of the atmosphere in this elevated zone, and thus have important meteorological significance. These movements are quite extraordinary. Not infrequently the currents at different heights flow in diverse directions and the train rapidly becomes zigzag. Sometimes it becomes tortuous, implying much turbulence. The velocities greatly vary and are sometimes very notable, not very infrequently reaching 100 miles an hour; even 300 miles per hour have been authoritatively reported. On the whole, the velocities seem to be higher than those which commonly prevail at lower altitudes. These high velocities, of course, are to be interpreted in the light of the great tenuity of the air. These swift, diverse, and turbulent currents seem to put out of court those mathematical deductions relative to the constitution of the upper atmosphere which are based on the assumption of its quiescence. Unfortunately these have found an unwarrantable place in meteorological literature.

The surficial diastrophic Zone

The broad black band of Diagram IV represents the surface of the earth incidentally, but its special purpose is to call attention to a dynamic zone in which the potential resistance to deformation has three distinctly different values in the six cardinal directions—a matter of moment in the study of the earth's surficial diastrophism. Displacement upward encounters little more than the resistance of the atmosphere and the weight of the material displaced; displacement in the four horizontal directions encounters the much more considerable resistance of the terrane itself, while displacement downward encounters the almost insuperable resistance of the solid earth-body. These diversities of potential resistance stand in sharp contrast to the four free sides and two stressed sides usually involved in laboratory experiments. The results of such experiments, therefore, need scrupulous qualification in their application to natural diastrophism. These distinctions of potential resistance are not wholly confined to the surficial zone; they are merely most pronounced there; in a declining way, they hold in respect to the deeper horizons.

This zone of differential resistance is closely related to the zones of fracture and flowage made familiar by the work of Van Hise and Leith. These, however, are primarily matters of texture and structure and secondarily of pressure. Like the preceding, though in a different sense, they are not strictly surficial, as pointed out by Leith in his recent vice-presidential address, though, like the preceding, they are most pronounced in the surficial zone.

Because of the special influences of the surficial zone, it has become a question how far the special forms of yielding seen at the surface are simply expressions of surficial dynamics and how far they are reliable signs of the agencies which primarily actuate the diastrophism. To throw light on this and related questions, a special mode of study has come into use in which the *reliefs* are made the *key* to the inquiry, the effort being to deduce from these the amount of surface shortening, the *depth,* and the *under-configuration* of the shell actually deformed, and so reach an approximation to the totality of the deformation in so far as it takes a distinctive surficial expression. This should aid in distinguishing such deformation as is merely an expression of surface conditions from such as constitutes a true index of the primary source of the diastrophism. The results of first trials of this special type of inquiry may be found in the papers of R. T. Chamberlin on the Appalachians of Pennsylvania and on the Rocky Mountains of Colorado.[7]

The Gravity-pull within the Earth

The interior of the earth is pervaded by more intense and more complicated dynamical qualities. The factors most needed to fill out our series are those that spring from a continuation of the gravity effects which, in the form of the sphere of control, was our starting point. These now assume two phases, namely, the continued *gravity-pull,* or attraction of the diminishing sphere, and the *rising gravity pressure,* or weight of the increasing superincumbent mass. In a sense, these are reciprocals, for as the one declines the other increases. The accelerating power of the earth is greatest at or near the surface. In some cosmological applications it is of acute importance to recognize that this maximum gravity is a variable in the sense that it increases with every stage of contraction of the earth, and this is not to be overlooked by students of relatively recent diastrophism; for, though the value of shrinkage may

[7] R. T. Chamberlin: The Appalachian folds of central Pennsylvania. Jour. of Geol., vol. xviii, 1910, pp. 228-51; The building of the Colorado Rockies. Jour. of Geol., vol. xxvii, 1919, pp. 248-51.

be small, all the curves dependent on gravity are involved and the effects are felt throughout the whole interior of the earth. From the gravity maximum, at or near the surface, the acceleration value declines both outward and inward, outward because the lines of pull are spread over greater space, inward because the lines of pull counterbalance one another. The best basis for forming a picture of the inward decline is found in the principle of the hollow sphere. To illustrate this, the line 1/2 V. of Diagram IV is drawn at 816 miles below the surface, which is the depth that divides the outer from the inner half of the earth, measured, of course, by volume, not by mass. This line may be taken as well as any other to define the inner side of a hollow sphere. Now, if a body is perfectly spherical, and if its layers are perfectly homogeneous in density in themselves (even though they differ from one another in density, as they usually do), the gravity of any symmetrical shell concentric to the center counterbalances or neutralizes itself as felt at any point within it. If the sphere is not perfectly spherical and homogeneous, corrections must be made according to the amount of deviation from sphericity and homogeneity. In the light of this, it is easy to see that as a body descends toward the center, the accelerating power of the earth on it falls off in proportion to the mass of the shell of matter left behind. The *speed* of an ideal body falling uninterruptedly to the center would, however, continue to increase all the way, but at a declining rate that would vanish at the center.

The Gravitative Pressure within the Earth

The rise of gravitative pressure within the earth is one of the most familiar of geologic themes and needs only a passing recognition here. It is dependent on the inherent weight of the matter and on its degree of compression. In a rough way, it ranges from one atmosphere, or megadyne, at the surface to about 3,000,000 atmospheres, or megadynes, at the center; but the precise distribution of the pressure is not yet determined. Geophysicists, mathematicians, and others have endeavored to derive as close an approximation to the curve of internal pressure as existing data will permit,[8] but the results are to be held as tentative until the qualifying conditions are better determined. The tenor of accumulating evidence implies that the conditions which affected the progressive self-compression of the body were more important than those which affected the original assortment of the material.

[8] Chamberlin and Salisbury: Geology, vol. I, p. 540.

The Spheroid of anomalous Effects on seismic Waves

By far the largest part of the earth's material transmits earthquake waves directly through the interior along curves that are related to chords, with sufficient fidelity to preserve the distinctness of the first and second sets of preliminary waves and thus render the record interpretable; but in the center of the earth there is a spheroid, embracing perhaps a fifteenth of its volume and a fifth of its mass, which in some way affects the transmission, so that the record is illegible. The line A. E. S. W. of Diagram IV outlines approximately this central spheroid. Neither the precise nature of the disturbing effect nor the cause of it has yet been satisfactorily determined. One of the more familiar suggestions is that this central spheroid is liquid; another that it is metallic. The first of these is naturally losing plausibility in proportion as evidence increases that this central portion, like the rest of the earth-body, is highly rigid. The metallic theory fits only very clumsily the growing evidence that the interior elasticity and rigidity rise faster than density, not only from the surface to the borders of this spheroid, as now well demonstrated, but all the way to the center, since this seems to be required to meet the mean rigidity and elasticity of the earth as a whole.

The Core of the Earth

Approaching the problem of this seismic anomaly from the cosmological side, the hypothesis that this central spheroid is simply the primitive core of the earth formed by the solidification of the nebular nucleus postulated by the planetesimal hypothesis seems an easy and natural solution. If the original nucleus concentrated itself along the gaseo-molten line of descent, in the modified way sketched in my recent discussion,[9] it would take on a more or less concentric structure similar to that logically assigned the whole earth by the old masters under the gaseo-molten hypothesis. The concentric layers, though homogeneous in themselves, would differ one from another in elasticity and density, and so they would be likely to divert the seismic waves by refraction sufficiently to seriously confuse the record. If this view shall find direct support as the evidence grows and skill in interpretation increases, it will aid in settling the as yet open question of the mass of the original earth nucleus. The spheroid of anomalous transmission is of the order of one-fifth of the total mass of the earth. This is not an improbable value for the nucleus, judged from quite independent considerations.

[9] Diastrophism and the formative processes. XII. The physical phases of the planetary nuclei during their formative states. Jour. of Geol., vol. xxviii, 1920, pp. 473-504.

We have now passed in review some of the more salient dynamic features of the greater earth. As pointed out at the start, the list can not now be made complete. In time there will have to be added spheres of influence springing from the electrical and magnetic properties of the earth. There will also have to be added a great complex of more intimate dynamic properties now more or less concealed within the body of the earth, the dynamic properties which to a large extent make the earth body what it is. All these, together with the outreaching influence gathered about the material earth, make up the greater earth.

Discussion

Professor Atwood: I would like to ask that Doctor Chamberlin speak a little further on the exchange of atmospheres between the earth and the sun. Is it likely to lead to enrichment or other notable change in our atmosphere?

Professor Chamberlin: From my point of view, the interchange looks rather toward uniformity, viewed in a large way, than to either enrichment or depletion. Unless there is some radical change in the sun, there should be no essential change in the equilibrium relations between the ultra-atmospheres of the sun and those of the earth. Of course, there are likely to be and have been minor variations. Some of these belong to the very nature of the equilibrating process and some to varying production or consumption of atmospheric material by the earth. The preponderance of logic, as well as geological and biological evidence, implies that the earth's atmosphere has been in rather steady equilibrium with the atmosphere of the sun. If the atmosphere of the earth, at any time or for any cause, is depleted, the sun should throw more molecules of the depleted sort into the atmosphere of the earth to restore the equilibrium; and *vice versa* if the earth's atmosphere is overenriched. In the secular action of this reciprocating process I find a satisfactory explanation of that remarkable steadiness of the earth's atmosphere in mean composition and mean temperature which has characterized the ages, despite some notable fluctuation, and which has made the continuity of the leading types of life a possibility.

Question: Was there a vast difference between the results obtained by you and Professor Moulton and those obtained by Sir George Darwin?

Professor Chamberlin: Not in so far as concerns the questions I have been discussing. Doctor Lunn, taking Sir George Darwin's data, found the dividing line between the two tidal spheres at 9,113 miles from the center of the earth; Doctor Moulton, using data of his own selection,

found it to be 9,241 miles. The difference is so trivial as to ma
results mutually confirmatory. Of course, in all such computation
is a margin of doubt. The mass of the earth is not accurately
mined, nor is the mass of the moon, nor are any of the basal data
accurate.

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GEOLOGY AND GEOGRAPHY IN THE UNITED STATES[1]

BY EDWARD B. MATHEWS AND HOMER P. LITTLE

(*Read before the Society December 29, 1920*)

CONTENTS

INTRODUCTION

The collection by the Research Information Service of the National Research Council of full schedules covering geologists and geographers and their activities has furnished an unusual opportunity for the study of the status of geology and geography in the United States at the present time. In order that the work might be more complete, these schedules,

[1] Abstract of report prepared for National Research Council. This article was printed as number 17 of Reprint and Circular Series of the National Research Council and 1,000 separates printed for the author, with pagination from 1 to 22.

Manuscript received by the Secretary of the Geological Society December 30, 1921.

which numbered approximately 900, were supplemented by a study of the membership lists of the Geological Society of America, the Paleontological Society, the Association of American Geographers, the Association of American Petroleum Geologists; a study of the manuscript of the new edition of "American Men of Science"; the catalogues of hundreds of universities and colleges; the bibliographies of North American Geology issued by the U. S. Geological Survey for the decade 1909-1918; and the personnel file of geologists prepared by the Division of Geology and Geography during the war and subsequent thereto. Moreover, to bring the information up to date, letters were written to a number of the leading institutions training geologists, asking for lists of young men who have been receiving special instruction during the last ten years. In this way there was accumulated information regarding nearly 2,500 men who have received instruction or shown interest in the combined subjects of geology and geography in America. Inasmuch as the study was part of the work of the Division of Geology and Geography of the National Research Council, it was appropriate to exclude from this study those whose residence was outside of the United States or whose subjects were more closely allied with engineering or chemistry than with the scientific aspects of geology and geography. The scrutiny of the schedules showed that some at least of those who had reported were interested in the subject merely as an avocation and these were excluded, as were certain engineers who, while using geological methods, were evidently more interested in the exploitation of mineral deposits than in their geological interpretation. There must naturally be more or less personal equation in the preparation of a list of this character, but in the present instance every effort has been made to give a generous interpretation to the names involved.

The final body of schedules and information on which the study of personnel is based consists of 1,275 names, representing that number of individuals in the United States interested in geology and geography and more or less active in the development of these sciences.

The facts which may be deduced from a study of the information will be treated under the following heads:

1. The personnel and its training.

2. The opportunities for education in geology and geography.

3. The publications dealing with North American geology and geography.

4. Organizations supporting research in geology and geography.

5. The lines of investigation now in progress.

Personnel and its Training

Personnel Lists

The personnel lists when tabularized gave the following facts, so far as they were obtainable: 1. Date of birth. 2. Place and date of first degree, graduate work, master's degree, or doctorate. 3. Present employment as teacher, Government or State geologist, museum curator, or commercial geologist. 4. Any change of interest in subject-matter where this was possible.

The classification of the personnel selected as above described showed the following figures concerning their educational equipment:

Training of Geologists

Educational advantages.—No collegiate record available, 125, or 10 per cent.

Bachelor of Arts or of Science only, 190, or 15 per cent.

Non-collegiate, with some special training, 35, or 3 per cent.

Graduate students without degrees, 230, or 18 per cent.

Master's degree only, 285, or 22 per cent.

Doctor's, with or without previous Master's, 410, or 32 per cent.

The figures show that the present geologists of the country are essentially college-bred men, 87 per cent having received collegiate degrees and 72 per cent a second degree, and over one-third of all of those listed have completed the requirements for a Doctor's degree. It may therefore be said that the profession is essentially a learned profession and not merely a trade.

A study of those regarding whom no collegiate record is available shows that of the 125 so listed only 11 are members of any of the professional societies. The remaining 114 might easily be omitted from consideration as without influence on the progress of science in this country, so far as this is represented by publications or participation in organized scientific activity. Among the 11 are included some of our most esteemed colleagues; but these are, with few exceptions, men of the older generation, when systematic instruction in geology was not so generally available as at present. The tabulation also shows that they are predominantly paleontologists.

Among those who have received instruction without collegiate degree are some of our most active scientists, devoted for the most part to paleontology, but the *majority* of this group appear to be interested in oil and are probably men who have attended courses at universities during the winter season in order to gain a little clearer insight into geological conditions affecting their industries rather than to prepare themselves for the life of a scientist.

Average annual flow.—The *average flow* of men into geology and geography is a matter of interest and the schedules have been studied from this viewpoint. The persons included are the men now living, and the true figures could only be gained by incorporating all of those who have died. Since geologists and geographers are proverbially healthy and the profession in this country dates numerically from 1870 or later, the conclusions drawn from living men are not far from what they would be if based on all geologists, living and dead, who have obtained their education during the last fifty years. Ten hundred and thirty-four Bachelors received degrees, according to the following table:

Geologists and Geographers arranged chronologically

	Bachelors	Masters	Doctors
Before 1870	36	7	6
1870-1874	20	8	4
1875-1879	22	9	
1880-1884	48	12	8
1885-1889	50	22	18
1890-1894	77	34	27
1895-1899	101	35	52
1900-1904	135	70	47
1905-1909	188	90	58
1910-1914	228	128	75
1915-1919	137	86	95

In general the Bachelor's degrees are taken at about age 22, the Master's at 24, and the Doctor's at 26. A few instances where the degrees were taken out of course modify these figures unduly and are not considered in the general statement.

When the number of Bachelor's degrees are plotted by years, the curve shows an average annual range of about 10 in 3 to 5-year cycles, with the maxima and minima points on a smooth curve from 1880 to 1908. During succeeding years there are wide fluctuations. The values vary from 27 in 1910 to 72 in 1912, back to 21 in 1915. Since the latter date the returns are too uncertain to forecast whether or not the annual flow will be resumed on its former scale. The excessive number in 1912 is entirely out of proportion and represents a marked departure from normality. The figures show that the number graduating from college each year who entered the ranks of geologists and have showed interest in the scientific aspects of the subject averaged less than 25 men during the last 40 years, increasing steadily from the 80's on to 1910. The subsequent studies of men receiving advanced degrees confirm the impression that the accommodations in universities for advanced training of a uniform stream of 50 to 60 per annum will meet the requirements for some years to come.

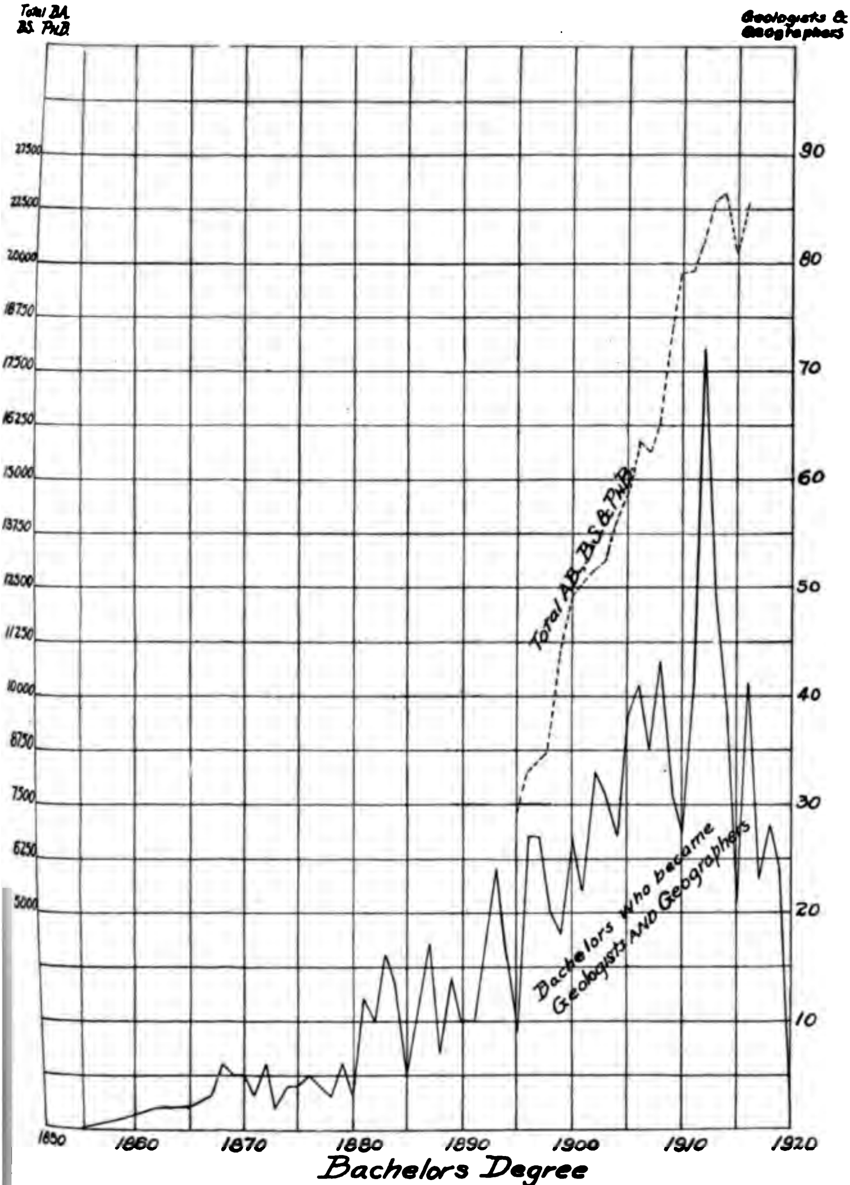

FIGURE 1.—*Bachelors in Geology and Geography compared with Total Bachelors*

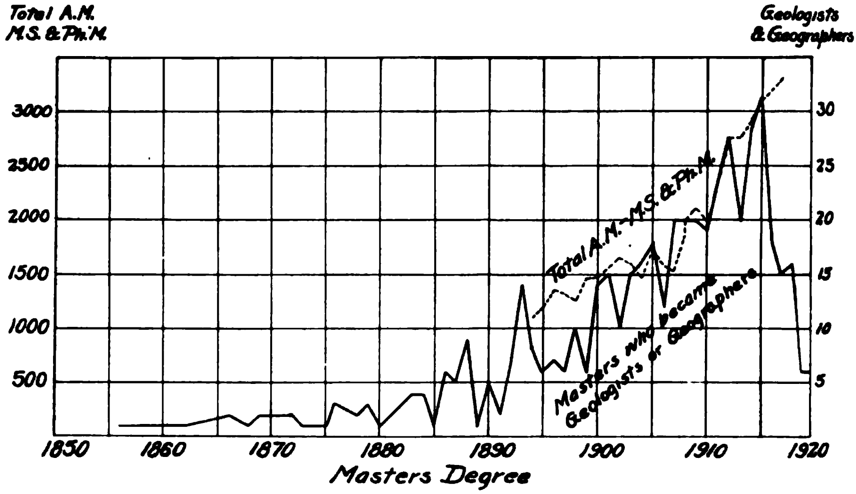

FIGURE 2.—*Masters in Geology and Geography compared with Total Masters*

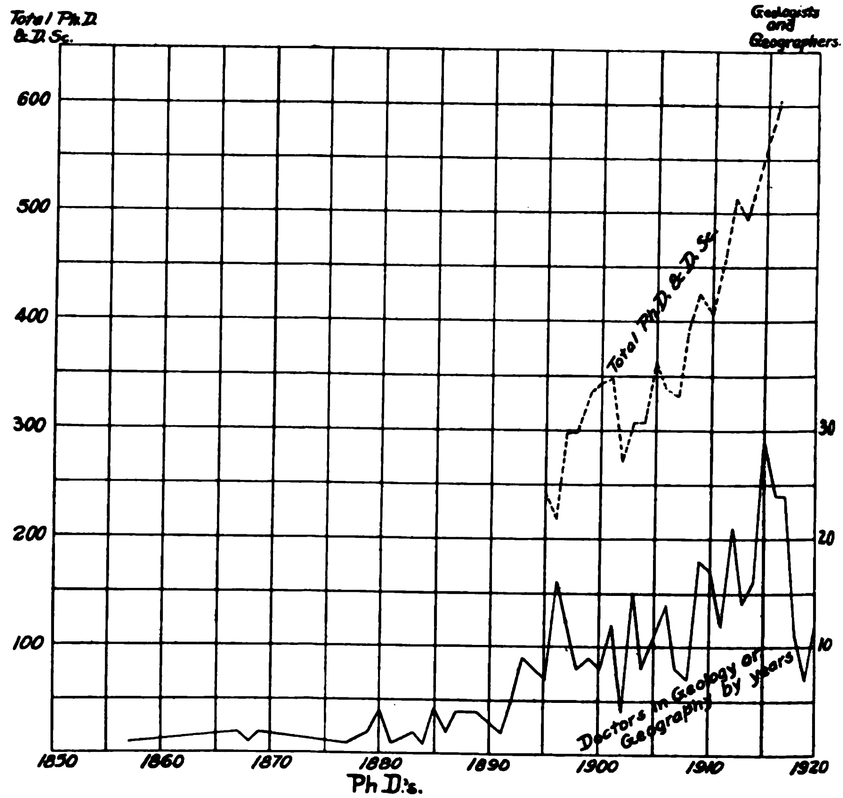

FIGURE 3.—*Doctors in Geology and Geography compared with Total Doctors*

Ratio between first and higher degrees.—The ratio between those taking the first and subsequent degrees in each decade is as follows:

	Bachelors	Masters	Doctors
1870-1879	100	40	9.5
1880-1889	100	35	24.5
1890-1899	100	33	44
1900-1909	100	50	33
1910-1919	100	59	46.6

For every 100 men now in geology who received collegiate training, 50 went forward to a Master's degree and 39 to a Doctorate. There is no well defined "drift" from decade to decade indicating that the number now taking advanced work is greater or less than formerly, though the figures suggest that there has been a tendency recently for a larger number to take the Master's degree than was the case during the "nineties."

Source of students.—Compared with the total number of degrees granted in American universities and colleges, the geologists show scarcely a "trace." Excluding technical degrees, the figures are approximately as follows:

Total A. B., B. S., and Ph. B	1895–1914	292,000	
Geologists taking Bachelor's degree		658	0.22 per cent
Total A. M., M. S., and Ph. M	1895–1914	36,950	
Geologists taking Master's degree		313	0.70 per cent
Total Ph. D. and D. Sc	1895–1914	7,160	
Geologists taking Doctor's degree		237	3.3 per cent

These ratios have remained fairly constant from year to year, with no appreciable "drift" away from the average. The increased percentage among the Doctors suggests that those who contribute to the development of the science are generally those with the highest training. The fall in the curves during 1915-1920 for geologists who have taken their Bachelor's degrees during 1915-1920 is doubtless due to the fact that they have not yet made their impression as professional workers and so have not been included as such in the lists. This is true in less degree of those receiving graduate work and Master's degrees during the same period. In the case of Doctors, it is different. The citing of dissertation subjects distinguishes those trained in geology. This, supplemented by the fact that lists of students have been obtained from most of the laboratories where men receive graduate training, suggests either that relatively fewer men are going forward in geology or that there has been slower recovery from war disturbances than in other subjects. Perhaps it is due to the fact that men in physics, chemistry, etcetera, were mobilized here for investigation in war problems and were thus enabled to continue their work on

dissertations while thus employed, while geologists were assigned to special tasks only indirectly related to their specialties.

Opportunities for Training

Sources of Information

The opportunities offered in the undergraduate courses of colleges and universities for the study of geology and geography determine largely the stimuli which cause men to choose these subjects as fields of research and the places where they may receive their technical training. The courses offered in geology and geography are quite distinct, except in the case of physiography, and the conditions for the two subjects are here treated separately.

Schedules from catalogues of 571 universities and colleges were examined and the actual number of hours of instruction listed, two hours of laboratory being rated as the equivalent of one hour of lecture or recitation. The results are no better than the catalogue statements, which sometimes suggest a stock-jobbing prospectus in their overemphasis of opportunities as compared with the facts. Inferences drawn probably represent the conditions more favorably than the actual facts warrant.

Educational Opportunities in Geology

Of the 571 institutions, 144, or 25 per cent, offer no instruction in geology, and 268, or nearly 50 per cent, nothing worthy of the name. These same institutions offer courses in chemistry, physics, or biology, but nothing to direct a student's interests toward geology, with the result that few graduates from them are now recognized geologists. Of the remaining institutions, 148 offer the equivalent of from one to two full year courses, 33 from two to three, and 25 from three to four; 97 give four or more years and 101 have actually had graduate students in geology. The last two groups include all the great privately endowed institutions, a large number of the State universities, and a few small colleges where geological traditions are strong.

Diagrams emphasize the numerical predominance of institutions giving little or no geology and those with strong departments. They show that the South Atlantic States, with 123 institutions, have only 16 giving enough instruction in the subject to suggest geology as a profession, and this inference is borne out by the fact that almost none of their graduates have taken advanced work. In the North Atlantic States the reverse is true. Here is more than the average opportunity to receive adequate undergraduate as well as graduate instruction, and the colleges of this

region have supplied a large proportion of the older geologists. The East Central States show many small colleges giving little or no geology and a number strong in undergraduate and advanced work. The West Central States, with a scattered agricultural population, show weakness, while the Pacific Coast offers excellent, though few, opportunities for collegiate and advanced work.

Graduate work is offered in many institutions, but where advanced degrees are seldom given this merely means that some promising bachelor has been held over as a student assistant. Over two-thirds of the institutions which have given advanced work are located in the North Atlantic and East Central regions, and over 75 per cent of these have given doctorates. Graduates who have subsequently received Doctor's degrees have come from 188 colleges, the largest number coming from Harvard, Yale, California, Cornell, Wisconsin, Hopkins, Chicago, Columbia, Indiana, Amherst, and Oberlin. Doctorates have been given in geology and geography by 37 institutions, although two-thirds of all the candidates received this degree from 7 universities and 40 per cent from 3 (Yale, Hopkins, and Chicago). While the movement from individual colleges to certain universities has been marked in a few instances, the movement on the whole has been quite general. Yale and Hopkins have granted degrees to Bachelors from 33 other institutions and Chicago to those from 30.

There is a general impression that most of the candidates for advanced degrees are now coming from the well equipped undergraduate departments of the higher-degree-granting universities, and that this practice is increasing. This has not been borne out by a study by decades of the educational history of recipients of such degrees. No general change in practice is shown. Tables prepared indicate that two-thirds of the Masters receive their degrees from the college at which they received their Bachelor's degree, while more than half of the Doctors come to the larger institutions from other places. To this general statement California, Indiana, Cornell, and Princeton are exceptions. At California 77 per cent of the Doctors were also Bachelors of that institution; at Indiana, 66 per cent; at Cornell, 64 per cent; at Princeton, 62 per cent; and at Harvard, 54 per cent.

Percentage of Graduate Students, Masters, and Doctors in Geology and Geography drawn from local Alma Mater in eleven Universities

	Graduate students without degrees [2]				Masters [2]				Doctors			
	1880-1889	1890-1899	1900-1909	1910-1919	1880-1889	1890-1899	1900-1909	1910-1919	1880-1889	1890-1899	1900-1909	1910-1919
California	..	..	..	40	..	0	50	61	..	66	100	63
Chicago	..	12.5	0	20	..	0	33	38	..	0	23	23
Columbia	0	0	12	25	0	0	14	50	..	100	0	33
Cornell	50	..	25	..	..	0	50	7	..	0	66	70
Harvard	0	0	11	14	50	48	35	37	100	37	42	60
Hopkins	0	0	0	9	..	..	..	0	50	0	25	38
Iowa	..	0	..	100	..	100	75	50	..	..	..	100
Minnesota	0	..	..	20	..	100	33	58	..	100	..	0
Princeton	..	100	100	100	..	..	100	0	100	100	..	25
Stanford	..	..	0	100	..	50	0	71	0	0	50	33
Yale	..	0	33	21	..	100	0	80	..	85	23	18

[2] These figures are less reliable than those for Doctors, since the records available are less satisfactory.

COMPARISON WITH 1893-94 CONDITIONS

A comparison of *changes in opportunities* for the study of geology in the universities and colleges of the United States between the years 1894 and 1920 may be vividly shown by a comparison of our figures with those of T. C. Hopkins[3] for the year 1893-94. Forty-nine more colleges offered geology in 1920 than in 1894, an increase of 13 per cent, and 60 more had separate departments, an increase of 115 per cent. Fewer colleges offered geology in 16 States in 1920 than in 1894, but in no case did a State show fewer separate departments. The former may be looked on as a healthy condition and may well indicate merely greater frankness on the part of many small colleges. The gain in separate departments probably is even greater than indicated, for Hopkins seems to have been over-lenient in his interpretation of what constitutes a department. For instance, to bring Massachusetts' total to eight, several colleges giving not over a year of geology were included, so far as can be judged from his discussion.

Pennsylvania furnishes a striking change for the better. In 1894 the State was credited with no separate college department, while in 1920 she had six, all of considerable strength. Ohio shows fully as striking a change by a decided gain in the number of smaller institutions. The development of separate departments in State institutions is also noticeable. Rutgers College and State-supported universities of twenty States (Vermont, Pennsylvania, Georgia, Mississippi, South Carolina, Tennessee, Iowa, Arkansas, Louisiana, New Mexico, Oklahoma, Colorado, Montana, North Dakota, Wyoming, Arizona, Idaho, Nevada, Oregon, and Washington) all register a decided increase in the appreciation of geology.[4]

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[3] T. C. Hopkins: Report of the Commissioner of Education, 1893-95, pp. 819 et seq. Washington, 1896.

[4] For changes within the science itself, particularly in attention given applied geology, the reader may be referred to the paper by A. H. Brooks in the Journal Washington Academy of Sciences, vol. II, 1912, pp. 23-48, and to the chapter in the present article dealing with research. Brooks' article was republished in the Smithsonian Annual Report, 1912, pp. 329-352.

Geology in Colleges and Universities of the United States

States	Hopkins, 1894: Geology a separate department — Name of college	No.	Geology given, no separate department	Total	Mathews and Little, 1920: Geology a separate department — Name of college	No.	Geology given, no separate department	Total	Net gain or loss 1894-1920: Separate department	No separate department
North Atlantic Region:										
Connecticut	Wesleyan, Yale	2	4	6	Trinity, Wesleyan, Yale	3	5	8	1	1
Delaware	....	0	2	2	....	0	1	1	0	−1
District of Columbia	Columbian University	1	4	5	George Washington	1	4	5	0	0
Maine	Colby	1	4	5	Colby	1	3	4	0	−1
Maryland	Johns Hopkins University	1	8	9	Johns Hopkins University	1	10	11	0	2
Massachusetts	Amherst, Harvard, M. I. T., Tufts, Williams—?,—?,—?	8	11	19	Amherst, Harvard, M. I. T., Mt. Holyoke, Radcliffe, Smith, Tufts, Wellesley, Williams.	9	15	24	1	4
New Hampshire	Dartmouth	1	2	3	Dartmouth	1	3	4	0	1
New Jersey	Princeton	1	2	3	Rutgers, Princeton	2	6	8	1	4
New York	C.C.N.Y., Colgate, Columbia, Cornell, Hamilton, Rochester, St. Lawrence, Union, Vassar.	9	22	31	Barnard, C. C. N. Y., Colgate, Columbia, Cornell, Hamilton, New York Univ., Rochester, St. Lawrence, Syracuse, Union, Vassar.	10	32	42	1	10
Pennsylvania	Boys Central High School	1	24	25	Bryn Mawr, Lafayette, Lehigh, Penn. State, Univ. of	6	37	43	5	13

Rhode Island	Brown	1	2	3	Brown	1	2	3	0	0
Vermont		0	2	2	Univ. of Vermont (?)	1	4	5	1	2
	Total	26	87	113		36	122	158	10	35
South Atlantic Region:										
Alabama	Univ. of Alabama	1	6	7	Univ. of Alabama	1	5	6	0	−1
Florida		0	3	3		0	4	4	0	1
Georgia		0	8	8	Univ. of Georgia	1	13	14	1	5
Mississippi		0	4	4	Miss. Agri. and Mech. College	1	9	10	1	5
North Carolina	Univ. of North Carolina	1	8	9	Univ. of North Carolina	1	16	17	0	8
South Carolina		0	8	8	Univ. of S. Car., Clemson	2	11	13	2	3
Tennessee		0	19	19	Univ. of Tennessee, Vanderbilt	2	16	18	2	−3
Virginia	Univ. of Virginia	1	9	10	Bridgewater, Univ. of Virginia, Virginia Poly.	3	13	16	2	4
West Virginia	Univ. of West Virginia	1	3	4	Univ. of West Virginia	1	4	5	0	1
	Total	4	68	72		12	91	103	8	23
East Central Region:										
Illinois	Chicago, Northwestern, Illinois	3	20	23	Chicago, Northwestern, Illinois	3	19	22	0	−1
Indiana	Univ. of Indiana	1	13	14	Earlham, Univ. of Indiana	2	11	13	1	−2
Iowa		0	17	17	Ames, Cornell, Iowa State	3	16	19	3	−1
Kentucky		0	9	9	University of Kentucky	1	5	6	1	−4
Michigan	Univ. of Michigan, Michigan Sch. Ms.	2	11	13	Univ. of Michigan, Michigan Sch. Ms.	2	7	9	0	−4
Minnesota	Univ. of Minnesota	1	5	6	Univ. of Minnesota	1	9	10	0	4
Missouri	Univ. of Missouri	1	19	20	Drury, Missouri Sch. Ms., Univ. of Missouri, Washington Univ.	4	11	15	3	−8
Ohio	Ohio State, Western Reserve	2	30	32	Case, Denison Univ., Mt. Union, Oberlin, Ohio State, Ohio Wesl., Univ. of Cinn., West. Res., Wooster.	9	32	41	7	2
Wisconsin	Beloit, Univ. of Wisconsin	2	7	9	Beloit, Lawrence, Univ. of Wis.	3	7	10	1	0
	Total	12	131	143		28	117	145	16	−14

Geology in Colleges and Universities of the United States

States	Hopkins, 1894				Mathews and Little, 1920				Net gain or loss 1894-1920	
	Geology a separate department		Geology given, no separate department	Total	Geology a separate department		Geology given, no separate department	Total	Separate department	No separate department
	Name of college	No.			Name of college	No.				
South Central Region:										
Arkansas		0	5	5	Univ. of Arkansas	1	6	7	1	1
Louisiana		0	9	9	Louisiana State	1	4	5	1	−5
New Mexico		0	2	2	Univ. of New Mexico, New Mexico Sch. Ms.	2	3	5	2	1
Oklahoma		0	1	1	Univ. of Oklahoma	1	5	6	1	4
Texas	Univ. of Texas	1	9	10	South. Methodist Univ., Univ. of Texas.	2	13	15	1	4
	Total	1	26	27		7	31	38	6	5
West Central Region:										
Colorado	Colorado Sch. Ms., Colorado Col.	2	6	8	Colorado Sch. Ms., Colorado Col., State Teachers College. Univ. of Colorado.	5	8	13	3	2
Kansas	Univ. of Kansas	1	16	17	Univ. of Kansas	1	13	14	0	−3
Montana		0	2	2	St. Sch. Ms., Univ. of Montana	2	3	5	2	1
Nebraska	Univ. of Nebraska	1	8	9	Nebraska Wesleyan, Univ. of Nebraska.	2	9	11	1	1

North Dakota		0	3	3	Univ. of North Dakota, North Dakota Agri. Col.	2	3	5	2	0
South Dakota	Univ. of South Dakota, Yankton.	2	6	8	St. Sch. Ms., Univ. of South Dakota.	2	5	7	0	−1
Wyoming		0	2	2	Univ. of Wyoming	1	1	2	1	−1
	Total	6	43	49		15	42	57	9	−1
Pacific Coast Region:										
Arizona		0	1	1	Univ. of Arizona	1	1	2	1	0
California	Univ. of Calfornia, Stanford	2	7	9	Mills, S. California, Stanford, Univ. of California.	4	10	14	2	3
Idaho		0	1	1	Univ. of Idaho	1	1	2	1	0
Nevada		0	1	1	Univ. of Nevada	1	1	2	1	0
Oregon		0	8	8	Univ. of Oregon, Oregon Agri. Col.	2	5	7	2	−3
Utah	Univ. of Utah	1	1	2	Utah Agri., Univ. of Utah	2	2	4	1	1
Washington		0	4	4	Washington State, Univ. of Washington.	2	4	6	2	0
	Total	3	23	26		13	24	37	10	1
	Grand total	52	378	330		111	427	538	59	49

NOTES

Massachusetts.—Possibly Boston University should be included under 1920.
New York.—Possibly Hunter College should be included under 1920.
Georgia.—Chair vacant 1920. Temporarily in charge of Professor of Chemistry.
Oklahoma.—Indian University of Indian Territory is the college giving geology previous to 1894. Two others offered it in 1895.
Colorado.—Colorado College, Department of Geology, suspended in 1918-1920.

EDUCATIONAL OPPORTUNITIES IN GEOGRAPHY

The figures for geography are so eloquent of the lack of opportunities in every State and in all regions that there is little need of attempting to interpret them in detail.

Commenting briefly on the distribution of geographic instruction, the most noticeable feature is the great dearth of it in the South. No institution of the South Central region gives as much as two years' work in the subject, and only one of the South Atlantic region gives as much as three years; this is the George Peabody College for Teachers. In the country as a whole, 401 colleges out of 571, or 70 per cent, offer no geography, and if physiography be considered geology, then 466 out of 571 colleges, or 81 per cent, offer no geography; or, stated positively, 105 institutions give all the college instruction in geography this country offers, and of these only 31 offer more than two years of geography as commonly understood.[5]

Of the work given by the 105 institutions, much consists of half-year courses in meteorology or commercial geography. A rough count[6] shows the following:

55 colleges offer courses in commercial geography.
43 colleges offer courses in meteorology.
27 colleges offer courses in geography of North America.
19 colleges offer courses in influence of geography on history.
17 colleges offer courses in climatology.[7]
16 colleges offer courses in the geography of Europe.
11 colleges offer courses in the geography of South America.
6 colleges offer courses in the geography of Latin America.
5 colleges offer courses in the geography of Asia.
1 college offers courses in the geography of Africa.

Advanced instruction is very meager. Only nine institutions offer courses of four years or more (California, Colorado State Teachers' College, Chicago, George Peabody College for Teachers, Harvard, Nebraska, Pennsylvania, St. Elizabeth's, New Jersey, and Wisconsin) and of these, two are colleges for teachers and one a Catholic woman's college with no instructor designated. This leaves only six (California, Chicago, Columbia, Harvard, Nebraska, and Wisconsin) to train students desiring advanced work, and among these there is much variance in the opportunities

[5] Hereafter in this paper geography does not include physiography unless specifically so stated.

[6] Courses offered by physics departments have not been looked for and not many of them are included. For a detailed study of meteorology in colleges see C. F. Brooks, Monthly Weather Review. vol. 47, 1917, pp. 169-170.

[7] Many of them combined with meteorology.

offered. Chicago is the best organized and most complete; Columbia is strong in industrial geography. Every region except the South Central has at least one college or university offering four years or more of work. In this connection attention may well be called to a recent paper in the Journal of Geography,[8] in which the "geography of college grade" as offered by the normal schools of the Middle States is reviewed in detail, with the conclusion that, "in general, normal schools offer the logical place to begin specialization in geography." At present, "geography stands by itself as an independent department in nearly every one of the Middle States normal schools," but in the reorganization of these which is already beginning there "will be a strong effort to include it (geography) under a department of science and perhaps mathematics. . . ." Such an outcome would put an additional burden on the colleges as standard-bearers of geography as a distinct science and add to the significance of the figures presented in this paper.

Publications dealing with North American Geology and Geography

STUDIES BY MR. A. H. BROOKS

Bibliographic lists and pages of publications are poor criteria for determining the value or number of contributions to a science, but they do give some evidence of scientific activities. An exhaustive analysis of publications, even for a single year, would not yield results commensurate with the labor involved. Fortunately, the U. S. Geological Survey issues annual bibliographies of North American Geology in which the articles are numbered and classified. A study of these lists was made by A. H. Brooks[9] for the years 1886-1909, and this has been extended to the year 1918 by an analysis of publications listed for the decade 1909-1918. The combined study shows a fairly steady increase in the number of articles listed, from less than 300 in 1886 to 1,350 in 1903. From that date to 1914 there was little or no increase, the annual numbers ranging from 1,150 to 1,400 between 1903 and 1910. Since 1910 the number has fallen to less than 1,100. It is instructive to note that, although these lists as analyzed by Brooks showed 47 per cent devoted to "applied geology" in 1909, the falling off in the curve of literary production coincides with the beginnings of the oil activities during the first decade of this century. Probably no period has been more prolific of high-grade accurate work in geology, especially in "applied geology," and this falling off in the record-

[8] Clyde E. Cooper: Status of geography in the normal schools of the Middle West. Journal of Geography, September, 1920.

[9] Journal, Washington Academy of Sciences, vol. II, 1912, p. 20.

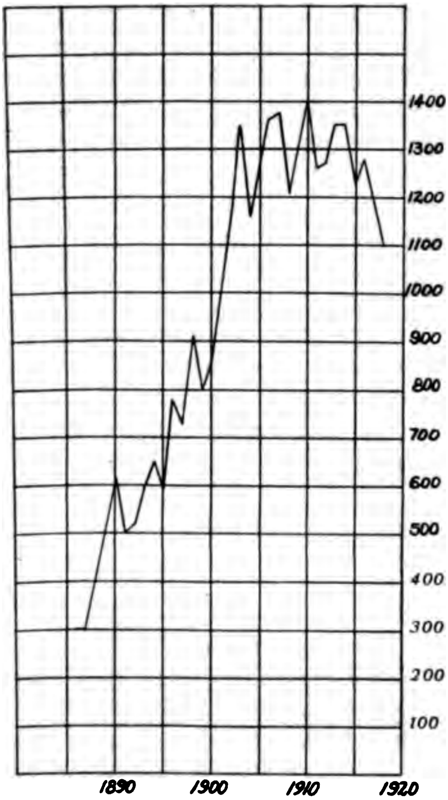

FIGURE 4.—*Number of Articles published on North American Geology*

ing of scientific results and the advancement of new scientific principles from the newly acquired facts confirms the statement of Brooks, that "there is, however, grave danger that, carried away by the present fervor of practical results, we may lose sight of our scientific ideals."

VOLUME

These bibliographic lists for the decade include 2,156 authors, who wrote 12,559 articles consisting of 414,430 pages ranging from duodecimo to elephant folio. Of the authors, nearly 1,000 have not been included in our personnel lists because of death, nationality, profession, or insignificance of geological contribution. Approximately 45 per cent of all the articles listed are less than 5 pages in length, over 65 per cent less than 15 pages, 85 per cent are under 50 pages, and less than 1 per cent over 500 pages. Considering the descriptive character of most geological and geographical papers, little real scientific matter is to be expected in the shortest articles. This generalization has been confirmed by an examination of many of the short papers. The annual production of papers on the geology of North America, exclusive of binding and advertising pages, might be estimated at something like 10 to 12 shelf feet a year.

SUBJECT-MATTER

The subject-matter of the publications listed in Bulletin 698 (1918) may be classed as follows:

General, including addresses and bibliographies	7 per cent
Economic	45
Dynamic and structural	7
Physiographic, glacial, and pedology	6

Areal, historical, and stratigraphic	11 per cent
Paleontology	12
Petrography and mineralogy	11
Water	1
	100

The year selected may have been abnormal, but the proportions are about the same as former statistics have recorded.

SOURCE

To test the source of supply of articles, the articles listed for 1914 were classified by pages published according to the probable source of funds, with the following results:

Based on Federal funds, approximately	9,500 pages, or	17 per cent
Based on State funds, approximately	15,500 pages, or	28
Based on university and foundations	11,000 pages, or	20
Based on Canadian official	10,000 pages, or	18
Based on individuals	9,000 pages, or	17
	55,000	100

The figures show that over 60 per cent of the published matter on the geology of North America is based on work financed by public funds, and the remainder largely by universities and foundations through grants or special facilities and free time for individual investigators. In these respects research and publications in geology and geography differ appreciably from those of some other subjects.

Organizations supporting Research in Geology and Geography

The organizations supporting research in geology and geography are quite different. For the former we have the U. S. Geological Survey and 40 State organizations, together with a few societies. On the other hand, for geography the support from Federal funds is slight and scattered through a number of departments and bureaus, such as the U. S. Coast and Geodetic Survey, the Hydrographic Office, the Department of Labor, the Board of Foreign Trade Advisers, and other agencies. Such geographic work as is done by State organizations is usually conducted by local geological surveys or those agencies interested in some particular subject which requires cartographic and distributional discussion.

The amount of money expended annually by the State and Federal survey may be appreciated from the accompanying table:

Expenditures

	1916	1917	1918	1919
U. S. Geological Survey.....	$1,454,923	$1,559,552	$2,276,063	$1,932,838
New England (as published)	9,765	9,916	31,884	7,074
Middle Atlantic " ..	39,027	12,705	25,208	42,020
East North Central " ..	145,161	135,585	130,998	143,941
West North Central " ..	65,360	33,107	34,382	45,084
South Atlantic " ..	86,817	86,948	69,073	85,871
East South Central " ..	60,821	50,585	41,413	58,668
West South Central " ..	23,787	22,902	30,802	25,215
Mountain " ..	18,267	29,536	26,881	37,457
Pacific " ..	89,222	127,809	193,681	102,103
For States omitted, estimated	100,000	125,000	125,000	100,000
	$2,093,150	$2,193,645	$2,985,385	$2,580,271

The gross amount of expenditures in geology each year by Federal and State governments exceeds $3,000,000. To this vast sum should be added the expenditures of the petroleum and mining interests, which would increase this amount many fold.

Public support for geography is largely incidental to other work and no figures are available. The amount, however, in this country, compared with the expenditures in other countries, is very small. On the other hand, local geographic societies, supplemented by individual benefactions, give some appreciable support to geography, although the gross amount is incommensurate to the interest in the subject, which has been growing rapidly during the last decade. With properly trained geographers, support of research in this subject will be easily secured as soon as the economic value of research in geography is more fully recognized. Even now the demand for trained geographers with sound judgment far exceeds the supply, and there is no use in enlisting the help of vocational schools, importing houses, and other powerful agencies until men can be supplied to meet the aroused demand. The experience of local geographic societies in arousing interest, and hence financial support, for projects of large dimensions suggests no likelihood of failure in securing support for geographic research when the projects are carefully developed and the ground previously prepared.

Lines of Investigation now in Progress

The reports of current research taken from schedules returned to the National Research Council are the least satisfactory part of the results. A comparison of the returns with the facts, as generally known, shows that they are not particularly significant, for some of the most active and

esteemed investigators have not recorded work which is known to be in progress. Others have apparently expressed their aspirations along many lines rather than investigations actually in progress in a way to produce results. Approximately 100 correspondents answered, indicating lines of current research, and a study of the returns shows that the work is well distributed throughout the fields of geology and geography. In general, the distribution is approximately the same as in the statistics for publications classified into the subjects named. There is, however, a marked relative decrease in the reported investigations in applied geology, particularly oil and gas, suggesting that many of our most active investigators are either debarred from mentioning their lines of activity for industrial reasons or because it is recognized that the refined scientific skill applied in investigations incident to their work is to be classed as practice of a scientific art rather than the promotion of scientific research.

Conclusions

The conclusions which follow are based on the present critical study of the conditions in geology and geography in America, a wide acquaintance with the active workers—Federal, State, and individual—the investigations in progress, and the material equipment and esprit de corps in our leading institutions. They may be summarized as follows:

1. The active workers in geology and geography are well trained, the majority with more or less specialized university training.

2. In geology the opportunities for training are, on the whole, sufficient to meet the vocational demands. The great bulk of the men complete their professional study at a limited number of institutions, well distributed throughout the country, and on these improvement of facilities should be localized.

3. There is need of more widely distributed and higher grade instruction in colleges to furnish the general educational advantages of courses in geology and to present the subject as a possible field for life work.

4. The recent excessive demand for geologists in "applied geology" has drawn students away from the universities before their training has been completed and has attracted their attention to the financial and technical aspects of the subject before they have become thoroughly grounded in the fundamentals.

5. This increased attention to the art of geology on the part of students and mature workers has arrested the development of the science, except in a few limited fields.

6. Geologic investigations are largely organized under Federal, State, institutional, or industrial agencies.

7. The opportunities for training in geography are inadequate to supply the specialists demanded. In our educational system there is also an unfortunate break in continuity of instruction in the subject in high schools and colleges, so that few become acquainted with its possibilities as a vocation.

8. The present lack of collegiate instruction prevents the presentation of the professional possibilities of geography and deprives students of a general training especially helpful in many fields of activity.

9. The productivity of the relatively few specialists in geography is great, covering a wide range of subjects, without very clear definition of the limits of geography toward other subjects, either as to method or matter.

10. Closer characterization in this respect would help administrative educators to understand the advantages accruing from the establishment of courses in collegiate and university geography and their proper departmental association.

11. Research in geography is largely unorganized and individual, except in the field of exploratory expeditions.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 32, PP. 249-266 JUNE 30, 1921

IGNEOUS GEOLOGY OF SOUTHEASTERN IDAHO [1]

BY GEORGE ROGERS MANSFIELD [2]

(Presented before the Society December 28, 1920)

CONTENTS

INTRODUCTION

The detailed examination by the U. S. Geological Survey of the Idaho Phosphate Reserve has made necessary the mapping of considerable areas occupied by igneous rocks. Such rocks are abundant in southeastern Idaho and present many interesting features. The igneous rocks of the Fort Hall Indian Reservation have already been described.[3] In the present paper it is proposed to summarize the igneous geology of the Cranes

[1] Manuscript received by the Secretary of the Society July 2, 1920.

[2] Published by permission of the Director of the U. S. Geological Survey.

[3] G. R. Mansfield and E. S. Larsen: Nepheline basalt in the Fort Hall Indian Reservation, Idaho. Washington Acad. Sci. Jour., vol. 5, no. 13, July 19, 1915, pp. 463-468.

G. R. Mansfield: The geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho, with a chapter on water resources by W. B. Heroy. U. S. Geol. Survey Bull. 713, pp. 57-61.

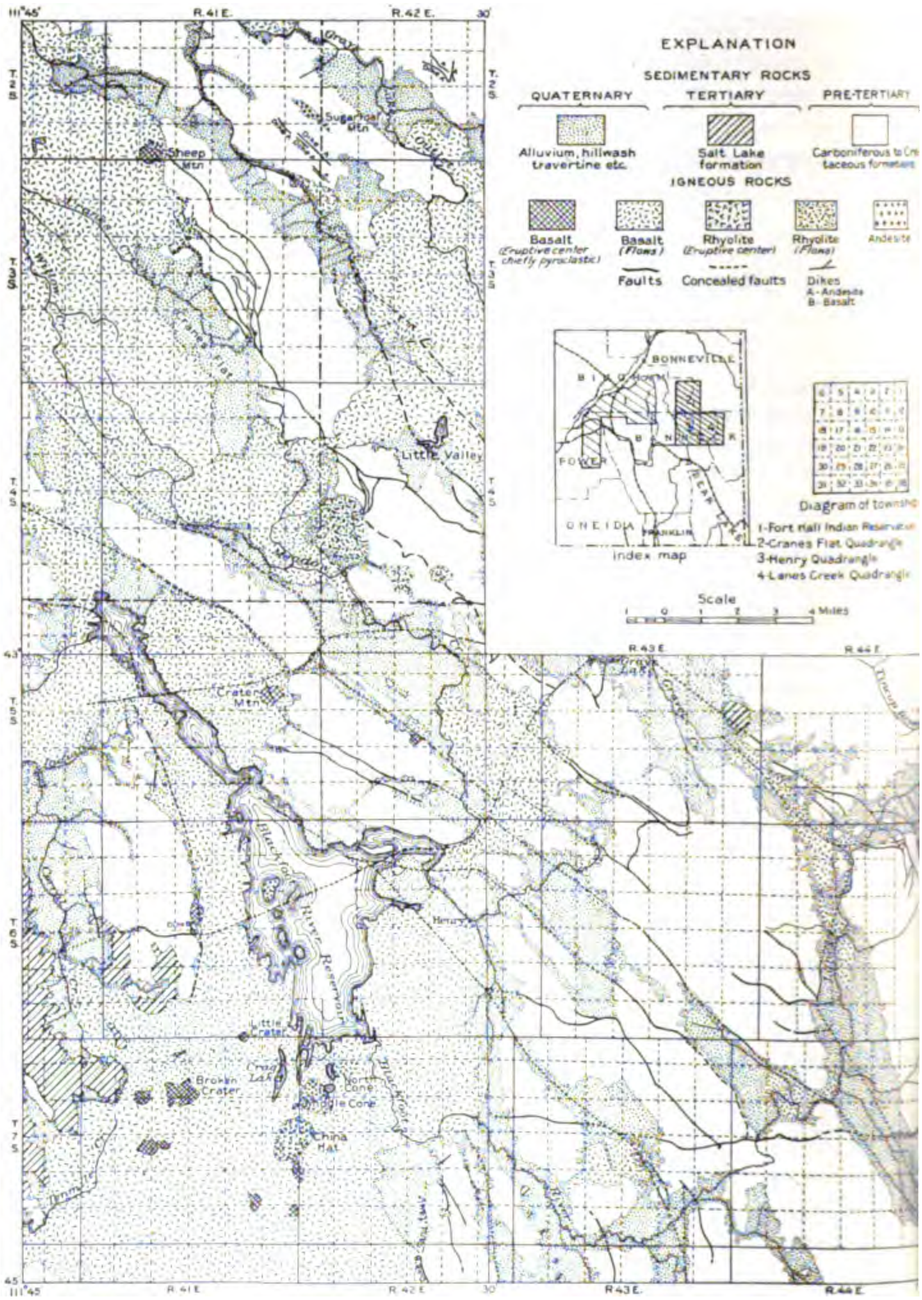

FIGURE 1.—*General geological Map of the Cranes Flat, Henry, and Lanes Creek Quadrangles, Idaho*

Flat, Henry, and Lanes Creek quadrangles, which lie in a group 15 miles or more east of the Fort Hall Indian Reservation and are shown in the accompanying map, figure 1.[4] A more extended account will be presented in a forthcoming detailed report on a larger region, which includes the quadrangles named.

General Distribution and Character of Rocks

The southeastern corner of Idaho is composed of folded and faulted sedimentary rocks that form prominent ridges with relatively broad intervening valleys and with northerly to northwesterly trend. Here and there small areas of igneous rocks occur, but these become more numerous and larger toward the northwest, so that in the Lanes Creek, Henry, and Cranes Flat quadrangles the ridges of sedimentary rocks become embayed and stand like rocky promontories or islands in a sea of basalt. The igneous rocks here represent marginal members or inflows of the great body of extrusives that constitutes the so-called Snake River lava plains.

Although there is considerable variation in the physical condition and appearance of the igneous rocks, they may all be referred to three groups, namely, hornblende andesite porphyry, rhyolite, and olivine basalt. Specimens and thin sections of these rocks have been studied by E. S. Larsen, Jr., and the late J. F. Hunter, to whom the writer is indebted for the petrographic descriptions given below.

Early rhyolitic Ash

Occurrences of rhyolitic or latitic tuff in the Wayan formation (Lower Cretaceous?) furnish the earliest record of igneous activity thus far recognized in the region. Two general occurrences have been noted, one in the southwest 1/4, section 20, township 5 south, range 44 east, in the Lanes Creek Quadrangle, and the other in the northeast 1/4, section 25, township 3 south, range 41 east, in the Cranes Flat Quadrangle. The rock has a greenish drab color and waxy texture and on broken surfaces shows flakes of biotite. Included with this rock are dark reddish to flesh-colored bands of somewhat coarser texture containing considerable feldspathic material, which is kaolinized on the weathered surface. Opaline silica has been deposited in some of the cracks. In thin section there are angular fragments of fresh plagioclase and quartz, biotite, and pieces of the walls of broken bubbles in a fine, feebly polarizing ground-mass. The source of this ash must probably remain a matter of speculation. On the assumption that the prevailing winds of Lower Cretaceous time had sim-

[4] Bannock County has been subdivided. The Henry and Lanes Creek quadrangles now lie in the newly organized Caribou County.

ilar courses to those of today, the material must have come from westerly sources. Igneous activity is reported from a number of regions at considerable distances to the southwest, west, and northwest during Lower Cretaceous time, but it seems to have been attended in general by comparatively little effusion. A single great outburst, the records of which may have been removed by erosion or concealed by later deposition, would very likely suffice to produce these ash beds.

Hornblende Andesite Porphyry

In the district here described the hornblende andesite porphyry occurs only in the northeastern part of the Cranes Flat Quadrangle. Rocks of this type, however, are rather widely distributed in the general region. They are known in the Portneuf Quadrangle, which adjoins the Henry Quadrangle on the west, and in the Fort Hall Indian Reservation. Caribou Mountain, in township 4 south, range 44 east, east of the Cranes Flat Quadrangle, owes its elevation, 9,854 feet, to the occurrence and relative resistance to weathering of intrusive igneous rocks described by St. John[5] as gray hornblendic trachyte. The same name is applied by him to the igneous rock at Sugarloaf Mountain, in the northeastern part of the Cranes Flat Quadrangle.

Most of the occurrences in this quadrangle are dikes with possibly some steeply inclined sills that vary in length from a few hundred feet to nearly a mile and in width from 4 to 20 or more feet. Sugarloaf Mountain is capped by a sill, or incipient laccolith, that appears to conform with the folding of the inclosing strata and has a maximum thickness of approximately 100 feet. In the Cranes Flat Quadrangle the andesite is found only in association with the Homer limestone member of the Wayan formation. The rock is generally deeply weathered and at many places has disintegrated to a yellowish or greenish-yellow gravel. The sill at Sugarloaf and some of the dikes furnish massive ledges, but at many localities there is no ledge, the position of the dike being indicated by yellow gravel and scattered pieces of weathered andesite. The sill at Sugarloaf is composed in part of relatively fresh rock which has resisted weathering and produced the sharply featured hill that bears the name. Two or three dikes are also prominent topographically.

The rock shows some variation in texture and mineral composition. It will suffice to describe two specimens. The first, M. 97-16, section 22, township 2 south, range 42 east, is macroscopically a light gray rock which shows plagioclase phenocrysts ranging in size to a maximum of

[5] Orestes St. John: Report of the geological field-work of the Teton Division. U. S. Geol. and Geog. Survey Terr., 11th Ann. Rept., 1879, pp. 396, 397.

one centimeter across, prominent but smaller hornblende prisms, and a little biotite in a ground-mass that has the appearance of a microgranular rock. The thin section shows that the rock contains large phenocrysts of andesine and pale green, zoned hornblende. There are a few crystals of apatite, with smaller crystals of plagioclase, biotite, and iron ore in a fine ground-mass that is chiefly plagioclase, but that probably includes some orthoclase and quartz.

The second specimen is M. 110-16, section 25, township 2 south, range 41 east, summit of Sugarloaf Mountain. In general appearance this rock differs from some of the other types in having no large feldspar or biotite crystals. Phenocrysts of hornblende one-half to one centimeter or more in length and locally in cruciform arrangement are conspicuous against a uniform finely crystalline gray ground-mass. In thin section the rock shows little, if any, biotite; the ground-mass is coarser than in some of the other types and contains considerable quartz and orthoclase. It might be called a hornblende-quartz latite porphyry, but is not very different from M. 97-16.

The hornblende andesite porphyry has not in this region been found in contact with any other igneous rocks or in close proximity to such rocks. Its deeply weathered condition is noteworthy and suggests that it may be older than the other types, none of which shows so much alteration. In the Fort Hall Indian Reservation andesitic tuffs of somewhat different composition from the andesites here described are locally overlain by rhyolite. The andesites of this district show some differences in age, for in section 22, township 2 south, range 42 east, the dikes that contain considerable biotite appear to cut the more hornblendic dikes, though contacts are not well defined because of weathering. The extremely weathered condition of both sets suggests that the difference in age is not great, and that in all probability these andesites all belong to a single epoch of igneous activity.

Rhyolite

The rhyolites of the district are confined to the Henry and Cranes Flat quadrangles. In the Henry Quadrangle the exposures include only the three large hills in the northwestern part of township 7 south, range 42 east, the largest of which is known as China Hat, and two islands in the Blackfoot River Reservoir, in the northeastern part of township 6 south, range 41 east. In the Cranes Flat Quadrangle the rhyolite occupies three areas in the southwestern part of township 4 south, range 42 east, the largest of which includes nearly two square miles. There are other minor occurrences.

The rhyolite occurs in the form of cones, flows, and dikes (?). There are also beds of volcanic ash. The most conspicuous occurrences are the three cones south of the Blackfoot River Reservoir, in township 7 south, range 42 east, called respectively China Hat, Middle Cone, and North Cone. The cones are built of pumiceous, glassy, and perlitic rhyolite, locally like obsidian and not usually distinguishable as separate flows. The greater weathering of some portions of the rhyolite and the relative freshness of other portions, since the rocks concerned are essentially of the same character, suggest that the cones represent a succession of eruptions rather than the products of single volcanic outbursts.

The siliceous rocks of the region, according to Mr. Larsen, show little variation and they probably represent in the main closely related flows. The chief differences are textural. The rocks are nearly white to pale quaker-drab, pink, gray, or even dark, rather porous, fluidal rhyolites, which include a few crystals of quartz and orthoclase with a little plagioclase. They carry also a very little biotite, which is partly altered, zircon, apatite, and iron ore. In some specimens the ground-mass is a perlitic or streaked glass; in others it is composed of beautiful, coarse spherulites. These commonly consist of concentric layers with gas cavities between some of the layers. Spherulites of a fibrous, very weakly birefracting zeolite, with an index of refraction of about 1.485, are abundant in these cavities (R. 69-16, section 29, township 4 south, range 42 east). In some specimens the spherulites are imbedded in glass. In others (R. 36-16, northeast ¼, section 14, township 6 south, range 41 east) the spherulites are made up of very coarse fibers, and these appear to grade into rude phenocrysts of micrographic intergrowths of quartz and orthoclase. The spherulitic varieties disintegrate rather readily into gravel. Tridymite, or a mineral that resembles it under the microscope, is abundant in some of the rocks.

The thickness of the rhyolite has not been determined. Owing to the local character of the occurrences, the thickness probably varies considerably from place to place. In section 30 (undesignated), township 4 south, range 42 east, canyons have been excavated more than 200 feet without cutting through it. The mass of the rhyolite in the three cones south of the Blackfoot River Reservoir is doubtless considerably greater than now appears, for their lower portions are concealed by basalt to an unknown depth, and by ash deposits and soil.

The rhyolitic cones south of the Blackfoot River Reservoir are surrounded by basalt, which is thus younger than much of the rhyolite. Similar evidence is furnished by basalt with inclusions of rhyolite on the northwest side of the pond in the southeast ¼, section 7, township 7

south, range 42 east. On the other hand, a ledge of rhyolite about 500 feet south of the center of the same section, on the north slope of Middle Cone, contains inclusions of basalt. Thus some of the rhyolite is younger than some of the basalt. Similar evidence is borne by the occurrence of rhyolitic ash above basaltic debris at several localities.

Olivine Basalt

The olivine basalt is the most widely distributed of the igneous rocks of the region. The Lanes Creek Quadrangle contains a number of separated areas of basalt, some of which may be connected under cover, but this can not safely be assumed. One of the larger areas is continuous with the Henry Quadrangle basalt, which, like a somber sea, separates mountainous sedimentary masses near the east and west borders of that quadrangle and surrounds the three rhyolitic cones south of the Blackfoot River Reservoir. The basalt is partially overspread in some places by hillwash and alluvium and elsewhere by soil and deposits of basaltic and rhyolitic ash. Locally these deposits have a thickness as great as 40 feet or more. This is particularly the case in districts south and west of the reservoir. The outcrops of basalt, however, are so numerous and so well distributed as to leave no reasonable doubt of the continuity of the rock-mass. Hence that district is all mapped as basalt.

More than half of the Cranes Flat Quadrangle is underlain by basalt, which is distributed in much the same way as in the Henry Quadrangle. The basalt forms two great areas nearly separated by the high sedimentary ridge that extends northwestward through the center of the quadrangle.

The basalt occurs in four general forms, namely, flows, cones or craters, dikes, and ash beds.

The great body of the basaltic rocks of the region is in the form of flows. In some places, as shown by well records, sedimentary deposits lie between the flows. In most places, however, nothing intervenes between the flows; their distinction is made on textural differences, which in turn have induced differences in weathering. Thus cliffs of massive basalt 10 to 20 feet high are locally separated by thin, platy basalt more or less concealed by blocky talus. The basalt has the characteristic columnar and cross-jointing with "ball-and-socket" weathering. The number of flows recognized in any one vertical section is usually not more than two or three, but the margins of flows form low cliffs on the broad basaltic areas; so that from favorable points of view the flows resemble dark waves, such as on a smaller scale are formed by successive sheets of water outpoured on a surface and then frozen.

Sprinkled here and there over the dark lava fields are cones that range in areal extent from a few acres to perhaps 10 or 12 square miles. They are composed of or accompanied by flows to a greater or less degree, but their more conspicuous features are cinder cones made up of basaltic fragments usually strongly red colored and ranging in size from buckshot to masses several feet in diameter. Usually a crater is present, but locally this has been breached, in some cones by explosion and in others by erosion.

There are two large lava cones, each surmounted by one or more cinder cones with craters. One of these, called Crater Mountain, is located in section 14, township 5 south, range 41 east, in the Henry Quadrangle. The cinder cone is composed of reddish and bluish black frothy basalt. It is about 3,000 feet in diameter at the base and rises more than 300 feet. The sides are relatively steep. The crater is about 1,700 feet in diameter and has a maximum depth of about 150 feet. The rim is uneven and marked by hills composed of scoria or bodies of more dense lava and 50 to 100 feet high. This is the largest cinder cone of the region. From beneath this surmounting cone the lava slopes away on all sides, but particularly to the south, west, and north. Eastward it abuts against the high limestone ridge and makes its way through the neighboring gap for nearly a mile. The whole accumulation covers an area of nearly 10 square miles and its summit rises about 900 feet above the surface of the Blackfoot River Reservoir.

The other large cone forms much of the mass known as Sheep Mountain, in the northwestern part of the Cranes Flat Quadrangle. The surmounting cinder cone is composite, but smaller than that of Crater Mountain. The underlying lava cone is difficult to delimit, but is estimated to occupy an area of about 12 square miles.

On the map, Plate I, the cinder cones are differentiated, but the lava is included with the basalt.

As in the case of the rhyolite, the dikes and ash beds are relatively subordinate features.

The cinder cones, though widely scattered, show a close correspondence in the general character of their component rocks. These are dark red-brown to dark gray in color. Most of them are highly scoriaceous and show few phenocrysts in the hand specimen. The microscope shows that the phenocrysts, which are chiefly olivine and feldspar with rare augite and magnetite, constitute from a very small proportion to about half the rock. The ground-mass is very fine and partly glassy to distinctly crystalline and is made up chiefly of augite, feldspar, olivine, and magnetite, with some apatite and hematite. A few erratic phenocrysts of resorbed

quartz are present in specimens M. 50-16 (southeast ¼ of southwest ¼, section 21, township 5 south, range 42 east), Henry Quadrangle, and R. 2-16 (northeast ¼ of southeast ¼, section 24, township 7 south, range 41 east). The rocks are rather fresh, except that the olivine is in part altered to iddingsite, and secondary analcite is present in the vesicles of some of the specimens.

Specimens have been collected from the basaltic flows in many parts of the district, a few of which are described below. Specimens M. 214-12 (southeast ¼ of northeast ¼, section 9, township 7 south, range 44 east) and R. 258-12 (southeast ¼ of southwest ¼, section 32, township 6 south, range 44 east), both from the Lanes Creek Quadrangle and examined by Mr. Hunter, are aphanitic and vesicular basalts. In thin section they are hypocrystalline, subophitic, and somewhat porphyritic, showing a few scattered phenocrysts of plagioclase, olivine, and augite. These are but little larger than the individuals of the ground-mass. The ground-mass is composed chiefly of laths of plagioclase, irregular grains of augite, olivine, magnetite, and a small amount of glass. The plagioclase has the approximate composition of labradorite.

Specimens M. 33-16 (northeast ¼, section 25, township 4 south, range 40 east) and R. 95-16 (southeast ¼, section 13, township 2 south, range 40 east), both from the Cranes Flat Quadrangle and examined by Mr. Larsen, are much alike. They are gray rocks with some small vesicles and have the appearance of rather coarse diabases. Crystals of feldspar, olivine, and augite are visible with a pocket lens. The microscope shows that the rocks are diabasic in texture, and that they are made up of calcic labradorite laths, olivine crystals, interstitial augite, and a little ground-mass, apatite, and iron ore. The ground-mass is a glass filled with skeleton crystals. A small amount of analcite is in the vesicles. The olivine is partly altered to iddingsite.

All the basalts of the region here described apparently contain olivine and may be classed as olivine basalts. There are, however, many differences in color and texture, particularly between the basalts that compose the cones and those that constitute the flows.

All are relatively fresh. Mechanical disintegration has occurred locally, as indicated by blocky talus piles at the bases of many cliffs. Chemical disintegration has produced little effect. The red color of the scoria is probably in part at least original. The alteration of some of the olivine to iddingsite and the development of analcite, as described above, together with the formation of white, calcareous coatings in favorable places, and the local development of brown weathered surfaces are the principal chemical alterations to be noted. The soils above the basalt are

not residual, so far as observed, but represent finely divided particles of drab-colored clayey material so arranged as to suggest wind-blown dust. Locally, the basalt is overlain by rhyolitic ash, hillwash, or alluvium.

The thickness of the basalt varies considerably from place to place and probably depends to some extent on the character of the underlying topography. The maximum exposed thickness is about 250 feet, but the actual maximum thickness is probably much greater.

Contact Metamorphism

No evidence of contact metamorphism has been observed in connection with the basalt and practically none with the rhyolite. The andesitic sill at Sugarloaf Mountain and some of the andesitic dikes farther northeast have produced a certain degree of metamorphism in beds of the Homer limestone (Lower Cretaceous?) with which they have come in contact. The main effect has been the induration or crystallization of the limestone for a few feet from the igneous rock. There has been some interpenetration of the limestone with silica and at two localities dark circular masses of chert about one-eighth inch in diameter give the rock a peculiar spotted appearance. These may be due to the replacement of poorly preserved tiny gastropods, such as occur in some beds of the limestone.

In the northwest 1/4, section 9, township 6 south, range 43 east, Lanes Creek Quadrangle, a metalliferous prospect in sandy limestone of the Wells formation (Pennsylvanian) furnishes a number of minerals, samples of which have been examined by Mr. Larsen. Among these are yellowish green garnet in masses and small crystals, quartz, chalcopyrite, malachite (?), and tabular hematite. The mineralization is purely local and points to the proximity of igneous rock, but none is exposed.

Epochs of Igneous Activity

There is evidence for at least five epochs of igneous activity. The possibility of three other epochs is also recognized, though these may prove to be identical with some of the five just mentioned.

(1) The early rhyolitic ash that now forms a poorly exposed indurated bed in the Wayan formation probably represents a single volcanic outburst or, at best, a brief epoch of igneous activity. The source of the ash is unknown, but probably lay west of the region here described.

(2) The hornblende andesite porphyry represents probably the first igneous activity within this actual region. The structural relations and character of the rock at Sugarloaf Mountain show that considerable erosion was necessary to produce the present exposures. This would mean

greater age for the andesite than for the other igneous rocks, which were outpoured on the surface and have not been greatly eroded. The andesitic tuffs of the Fort Hall Indian Reservation are much altered and represent the earliest igneous rocks recognized there.

(3?) The inclusion of basaltic fragments in rhyolite may mean that olivine basalt was erupted before the first outflows of rhyolite. The relative freshness, however, of both the basalt and the rhyolite and the practical identity in mineralogic character of the basaltic inclusions with the broad basaltic flows suggest that the inclusions are parts of the main flows and that the inclosing rhyolite belongs with the later rhyolitic extrusions.

(4) Much of the rhyolite that forms the cones and perhaps the greater part of the flows was extruded during the next epoch.

(5) Basalt surrounds the rhyolitic cones and floods much of the lower ground in the northwestern part of the region. Some of the basalt includes fragments of rhyolite. Although the basaltic outflows were probably in greater part of the quiet type, the numerous cinder cones and the basaltic ash at some localities indicate that some of the eruptions were explosive.

(6) A second rhyolitic epoch probably gave rise to the lavas that include fragments of basalt and supplied rhyolitic ash that here and there overlies the basalt. From the relatively smaller volume of the fresher flows recognized, this epoch was probably of shorter duration than the first rhyolitic epoch. The presence of ash beds indicates that the eruptions were in part of the explosive type.

(7?) A little basaltic flow on the northwest slope of Middle Cone, in the northwest ¼ of southwest ¼, section 7, township 7 south, range 42 east, suggests a possible basaltic episode later than the second rhyolitic epoch. The basalt with inclusions of rhyolite in the southeast ¼ of the same section tends to support such a view. Additional evidence is furnished by the presence of a basaltic ash bed between beds of rhyolitic ash in a cut bank of Blackfoot River, in section 16, township 7 south, range 42 east. These features may be the result of a single basaltic epoch, but in section 14, township 5 south, range 39 east, in the Portneuf Quadrangle, rhyolite with gentle easterly dip is both underlain and overlain by basalt, thus indicating two basaltic outflows with an intervening rhyolitic flow.

(8?) The most recent extrusive activity appears to have been rhyolitic. It is represented by deposits of rhyolitic ash, perhaps the higher bed of the Blackfoot River section above mentioned, and by the explosion craters now occupied by ponds between Middle Cone and North Cone, in town-

ship 7 south, range 42 east. Mounds of debris including both rhyolitic and basaltic fragments with some sedimentary material partly surround the craters. The craters and mounds are so fresh that they might easily have been formed within historic time.

With the exception of the earliest rhyolitic epoch and the doubtful epochs, the record of igneous activity in this region agrees fairly well with that in the Fort Hall Indian Reservation, but no nepheline-bearing rocks, such as were found there, have been found here.

Comparing the record of igneous activity in southeastern Idaho with the more extended record of the Yellowstone National Park,[6] some 70 miles or more to the northeast, it seems probable that the two major events of the Idaho record, the extrusion of great masses of rhyolite and basalt, were in general contemporaneous with the corresponding events of the Yellowstone Park. It is to be noted that in the latter region some basalt was extruded prior to the outflows of rhyolite. The deeply weathered hornblende andesite porphyry of the Idaho record may correspond with the early acid breccia of the Yellowstone Park, which is described as consisting mainly of hornblende andesite and hornblende mica andesite. The erosion and weathering which the Idaho andesite has experienced perhaps favor this interpretation rather than that of a correspondence with the late acid breccia of the park, which it doubtless also resembles.

Origin of the Igneous Rocks

The simplest view of magmatic differentiation as applied to the igneous rocks of this district is that these rocks were formed from an original magma of intermediate composition, from which came first the hornblende andesite porphyry, and then by continued differentiation the series of rhyolites and basalts. This conception would accord with the rule stated by Iddings,[7] "that in any period of volcanic activity the earliest eruptions are of rocks having an average or intermediate composition, and that subsequent eruptions are of magmas with more and more diverse compositions, the last eruptions producing the most diverse kinds."

Lindgren,[8] summarizing the extrusive activity of the Cordilleras, presents a different view of the problem. He divides the extrusives of the Cordilleras into two groups, one of which "embraces the volcanoes of the Sierra Nevada, the Cascades, innumerable vents in Nevada, the Yellowstone Park region, and the San Juan country, in southwestern Colorado.

[6] U. S. Geological Survey atlas, Folio 30, 1896.

[7] J. P. Iddings: Igneous rocks, vol. 1, p. 257. New York, 1909.

[8] Waldemar Lindgren: The igneous geology of the Cordilleras and its problems. Yale University, Silliman Foundation, 1913. Problems of American geology, pp. 234-286, p. 285. New Haven, 1915.

All these yield predominant andesite with considerable rhyolite and minor masses of basalt, and it seems fair to advance the hypothesis that they are caused by explosive action from the magmas of older granodioritic or quartz-monzonitic batholiths, which have had time to differentiate in their upper gas-charged 'cupolas,' or from satellitic intrusions of such batholiths. Wherever we find local intrusions in such volcanoes they appear to be of magma of intermediate composition." The other group includes "the Columbia River lavas, many fields in Nevada, and those of central and eastern Arizona. These eruptions go over into the type of latest Pliocene and of Quaternary age, in which only basalts were poured out. It seems probable that these eruptions are not connected with the granodioritic magmas, but are of more deep-seated origin."

In the region here described the hornblende andesite porphyry is apparently the oldest of the igneous rocks in place, and thus represents the first products of the magmatic intrusion of the region, perhaps before any significant differentiation had taken place, if the simpler view implied by the citation from Iddings is assumed, or it may represent a differentiation product from a granodioritic magma such as those postulated by Lindgren. No effusion appears to have occurred in this immediate region, but in the Fort Hall Indian Reservation considerable areas of andesitic tuff show that there were actual volcanic outbursts not far away.

The rhyolites and basalts may represent the products of further differentiation of a magma of intermediate composition or a granodioritic magma, but the basalts, according to Lindgren's view, more probably come from a different and more deeply seated magmatic source. The region has thus been underlain by at least one great body of rock magma or possibly by an earlier and a later magma at different depths. From these the igneous rocks here described have been derived. It is possible that further intrusions or effusions may develop from the same source, although present evidence points to the dying away of volcanism.

Modes of Eruption

GENERALLY EFFUSIVE IN CHARACTER

Most of the igneous rocks of the region are effusive, though a few dikes and sills and an incipient laccolith have been noted. The hornblende andesite porphyry in the Cranes Flat Quadrangle has been found only in intrusive form.

INTRUSION AT SUGARLOAF MOUNTAIN

St. John[9] regards the intrusion of the andesite at Sugarloaf Mountain

[9] Orestes St. John: Report of the geological field-work in the Teton division. U. S. Geol. and Geog. Survey Terr., 11th Ann. Rept., 1879, p. 356.

(his Station XVII) as the cause of the upheaval of the mountain. He says:

"Although the deposits in the immediate southwest slope of Station XVII are somewhat obscure, and withal so altered by metamorphic action as to render their examination difficult, yet their more favorable exposure in the opposite hillside to the west affords satisfactory data for the determination of the relations of the sedimentaries to the volcanic phenomena with which they are here associated. The igneous mass protruding in the crest of the ridge seems to have been forced up nearly in a vertical direction, carrying the sedimentary beds up with it instead of fracturing them at once, so that at the extremities of the upthrust they were not rent apart. But at the point of greatest tension they were partially fractured, the igneous matter following the crevice thus produced, as a wedge-shaped mass, which subsequent erosion has bared, and thus revealed the origin of the little anticlinal fold, of which it forms as well the nucleus."

Saint John's geologic structure section at Sugarloaf Mountain is reproduced in figure 2. More detailed study of the Sugarloaf district has shown that the Homer limestone into which the andesite is intruded is

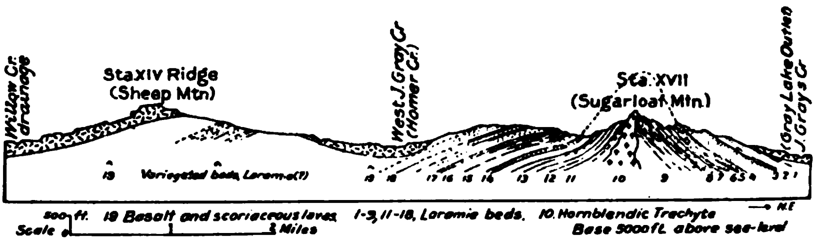

FIGURE 2.—*Saint John's structure Section through Sugarloaf Mountain*

folded into an inverted, fan-shaped synclinorium, of which the anticline at Sugarloaf Mountain is one of the minor folds. The intrusive body is a thickened sill or incipient laccolith that, in the northwestern extension of the mountain, arches with the strata; but beneath the summit the southwest limb of the anticline is so eroded that the sill is exposed as a southwest-facing cliff. These features are shown in the accompanying map and geologic structure section, figure 3.

The andesite shows no shearing and the minerals in thin sections show no strain. These facts indicate that the rock was not folded after its intrusion, but that it either followed structure lines already established or itself participated in the deformation of the associated strata. The latter view seems more probable, for Lindgren,[10] after a study of the Cordilleras, says:

[10] Waldemar Lindgren: Op. cit., pp. 282-284.

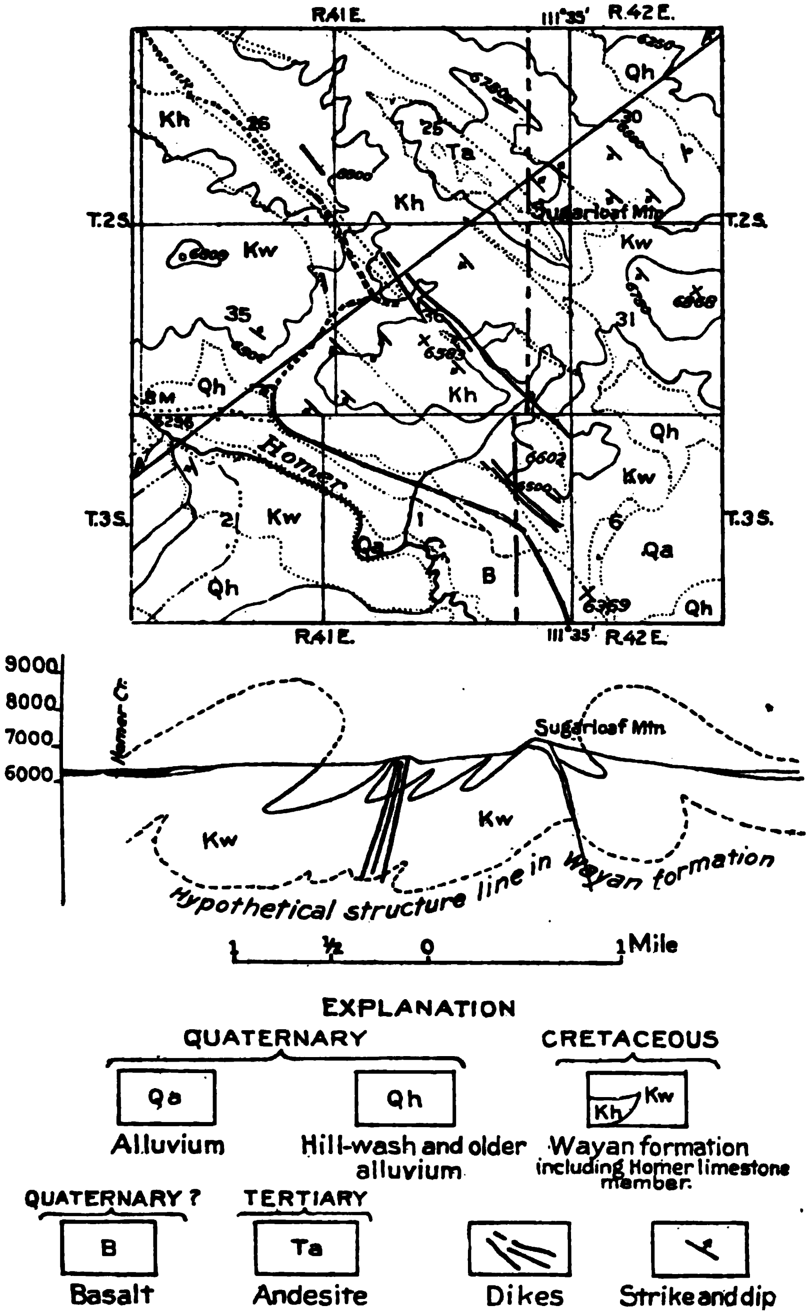

FIGURE 3.—*Map with geologic structure Section of the Sugarloaf Mountain District, Cranes Flat Quadrangle, Idaho*

"Everywhere intrusions correspond to uplifts, and the evidence, it seems to me, is entirely favorable to simultaneous uplift and intrusion. . . . Can we doubt that uplift was one of the consequences of batholithic intrusion? Is it not also probable that large areas of elevation in the Cordilleras are underlain by concealed batholiths?"

EXTRUSION OF RHYOLITE

The earlier extrusions of rhyolite that constitute probably the greater bulk of the rhyolitic masses show fairly definite relations to fracture or fault lines in many of their occurrences. The alignment of the cones and craters in the northwestern part of township 7 south, range 42 east, Henry Quadrangle, can scarcely be accidental. It doubtless marks a fissure or more probably the intersection of a northeast-southwest fissure with a set of fissures having a northwesterly trend. The rhyolitic islands in the Blackfoot River Reservoir lie in close proximity to a concealed fault believed to pass beneath the reservoir and to connect the transverse faults in township 6 south, ranges 41 and 42 east. The islands may mark the intersection of this fault with a northerly or northwesterly fissure perhaps continued northward from one of the cones. The flows in township 4 south, range 42 east, Cranes Flat Quadrangle, are also believed to overlie a fault. The later extrusions of rhyolite, so far as distinguished, were localized in general along the lines of previous rhyolitic activity.

EXTRUSION OF BASALT

Bradley[11] and Peale[12] regarded the craters near Soda Springs as the sources of the lavas of this region. Russell[13] also shared this view. Some of the craters named are doubtless those of the Henry and Cranes Flat quadrangles. The present study of the region has led to the view that these craters have played, on the whole, a relatively subordinate part, and that fissure eruptions were probably more important. Without doubt, both types of eruption have occurred here, but it is not possible from present data to evaluate the part played by each type. Great volumes of basalt have undoubtedly been outpoured from the volcanoes now called Crater Mountain and Sheep Mountain and probably lesser amounts from the smaller cones. On the other hand, the prevalence of faulting in the region and the alignment of some of the cones strongly suggest the importance of the part fissures may play. In some localities, as in section 16, township 3 south, range 41 east, Cranes Flat Quadrangle, and sections 18

[11] F. H. Bradley: Report of the Snake River Division. U. S. Geol. Survey Terr., 6th Ann. Rept. (1872), 1873, p. 204.

[12] A. C. Peale: Report of the Green River Division. U. S. Geol. and Geog. Survey Terr., 11th Ann. Rept., 1879, pp. 643-644.

[13] I. C. Russell: Geology and water resources of the Snake River plains of Idaho. U. S. Geol. Survey Bull. 199, 1902, p. 65.

and 30, township 5 south, range 43 east; Lanes Creek Quadrangle, basalt has emerged along recognized fault lines. Elsewhere, as in parts of the Lanes Creek Quadrangle, the basaltic hills south of Henry, in township 7 south, range 42 east, and in the basaltic hills and ridges west of Cranes Flat, in township 3 south, range 41 east, the occurrence of the basalt is such as to make doubtful its connection with existing cones or craters.

Succession of the Igneous Rocks

The succession of the igneous rocks of this region, as previously indicated, probably begins with an intermediate type, andesite, as in the successions of Richthofen and Iddings, and is followed by alternations of rhyolite and basalt, including at least two and possibly three outbursts of rhyolite and possibly two of basalt. The general conclusion of Lindgren,[14] that eruptions close with outpourings of basalt, does not seem to be sustained in this region. Here rhyolitic ash overlies basalt locally and the craters between the cones in section 7, township 7 south, range 42 east, are bordered by piles of mingled debris, chiefly rhyolitic. A similar condition was noted in the Fort Hall Indian Reservation, where a dark volcanic sand, composed of latitic lapilli, overlies basalt. It is possible that in each of these regions some flow of basalt later than these siliceous eruptions may exist beyond the district affected by the rhyolite, but no such flow has thus far been distinguished.

Relations of Igneous Rocks to Sedimentary Rocks

The beds of earlier rhyolitic or latitic ash in the Lanes Creek and Cranes Flat quadrangles, previously described, are not well exposed, but they appear to be interbedded with the Wayan formation and to share in its deformation.

The relations of the hornblende andesite porphyry to the accompanying sediments at Sugarloaf Mountain and vicinity have already been discussed. The folding of the strata is not noticeably greater at Sugarloaf Mountain than in many other parts of the field where igneous rocks are not exposed. Thus it would seem that the part played by the intrusion of the porphyry in the upheaval of the mountain was relatively insignificant, but the intrusion of the supposed concealed batholith from which the igneous rock was derived may have been an important factor in the general deformation of the region.

The rhyolite in the Cranes Flat Quadrangle overlies inclined strata ranging in age from Carboniferous to Lower Cretaceous (?). In the

[14] Waldemar Lindgren: Op. cit. p. 274.

adjacent Portneuf Quadrangle (township 5 south, ranges 39 and 40 east) it also overlies the Salt Lake formation (Pliocene?). The basalt bears a similar relationship to the pre-Quaternary strata, and in the Henry Quadrangle occupies depressions excavated in the Salt Lake formation. Both the rhyolite and basalt are overspread locally by the earlier Quaternary deposits.

Age of igneous Rocks

The age of the hornblende andesite porphyry at Sugarloaf Mountain may be judged only by its structural relations and present state of preservation. If contemporaneous with the folding, it dates back to the major deformation of the region, which occurred in post-Cretaceous or early Eocene time. It has already been suggested that the hornblende andesite porphyry may correspond with the early acid breccia of the Yellowstone National Park. This rock has been shown by its fossil plant remains to be of Eocene age. In the Fort Hall Indian Reservation[15] andesitic tuffs are overlain by or perhaps in part interbedded with white and yellow conglomerates probably to be correlated with the Salt Lake formation (Pliocene?). On the assumption that the andesites of the region are essentially contemporaneous, they are probably not later than early Pliocene and they may be as old as early Eocene.

In the Fort Hall Indian Reservation the ages of the rhyolite and basalt range apparently from Pliocene into early Quaternary. The similarity of the igneous succession in the Fort Hall Indian Reservation with that of the quadrangles here discussed has already been pointed out. Hence it seems probable that the igneous activities in the two areas which are neighboring parts of the same general region were essentially contemporaneous. In the Yellowstone National Park the rhyolite, which is believed to be essentially contemporaneous with that of southeastern Idaho, overlies the Canyon conglomerate, from which were taken bones identified by O. C. Marsh as part of the skeleton of a Pliocene fossil horse.

The rhyolitic ash of the Henry Quadrangle, though forming soil at a number of places, does not so clearly overlie the early Quaternary deposits as does the latitic ash of the Fort Hall Indian Reservation. However, the recent appearance of the craters in the eastern part of section 7, township 7 south, range 42 east, and of their accompanying debris suggests that their age is probably not greater than that of the latitic ash. The age here assigned to the rhyolite and basalt accords with that of the basalt of the general region as described by Peale[16] and Russell.[17]

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[15] G. R. Mansfield: Op. cit., p. 60.
[16] A. C. Peale: Op. cit., pp. 643-644.
[17] I. C. Russell: Op. cit., pp. 61 and 105.

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PRE-CAMBRIAN ROCKS OF MANITOBA [1]

BY F. J. ALCOCK AND E. L. BRUCE

(Read before the Society December 28, 1920)

CONTENTS

INTRODUCTION

The consolidated rocks of three-quarters of the Province of Manitoba are of pre-Cambrian age. Our geological knowledge of these rocks has

[1] Manuscript received by the Secretary of the Society March 19, 1921. Read by E. L. Bruce.

been derived from two types of exploration, namely, track surveys with geological notes, performed by Bell, Cochrane, Tyrrell, Dowling, and McInnes, and more detailed geological surveys made during recent years in the areas where active prospecting for minerals has been carried on. It is the object of the present paper to correlate as far as possible the more recent information which has been obtained. No attempt is made to apply the nomenclature adopted for the pre-Cambrian succession of any of the geological subprovinces along the southern border of the Canadian shield, and the only comparison offered is with the succession found in the Rainy Lake area of Ontario—a region which is geographically the nearest and geologically the most similar of any area outside the Province of Manitoba where detailed work has been done. It is also not to be assumed that the paper is a final statement of all the problems connected with the pre-Cambrian geology of Manitoba. Complete detailed work has been performed as yet in but few places, and future investigation will doubtless bring to light many new facts. The following discussion is, therefore, merely an attempt to collect, in summarized form, our present knowledge of the pre-Cambrian history of the province.

General Character of the Country

The southwestern part of Manitoba, underlain by flat-lying Paleozoic and Cretaceous strata, is separated from the northeastern part, of Ordovician and Silurian rocks lying in the James Bay basin, by a broad band of pre-Cambrian rocks which occupies three-fourths of the province. A few outliers of Ordovician dolomite are found in front of the low, irregular escarpment that marks the contact of the Paleozoic rocks of the southwestern section with the lower lying pre-Cambrian formations. The northeastern contact is in most places hidden by glacial and postglacial deposits.

The surface of the pre-Cambrian belt slopes gently from an elevation of about 1,200 feet in the western part of the province eastward to Hudson Bay. It presents the features so uniformly developed over the entire Laurentian plateau, the two most important of which are low relief and disorganized drainage. Only in few places do elevations rise more than 100 feet above the adjacent lakes and valley bottoms, and hills of greater height are prominent landmarks. In detail, however, the surface of the country is very irregular, consisting of low broken ridges separated by depressions in which lie lakes and muskeg swamps. The rivers are successions of lake expansions connected by streams with rapids, waterfalls, and, in places, narrow gorges. The lakes have many islands, and long, narrow bays give them a great length of shoreline in comparison to their

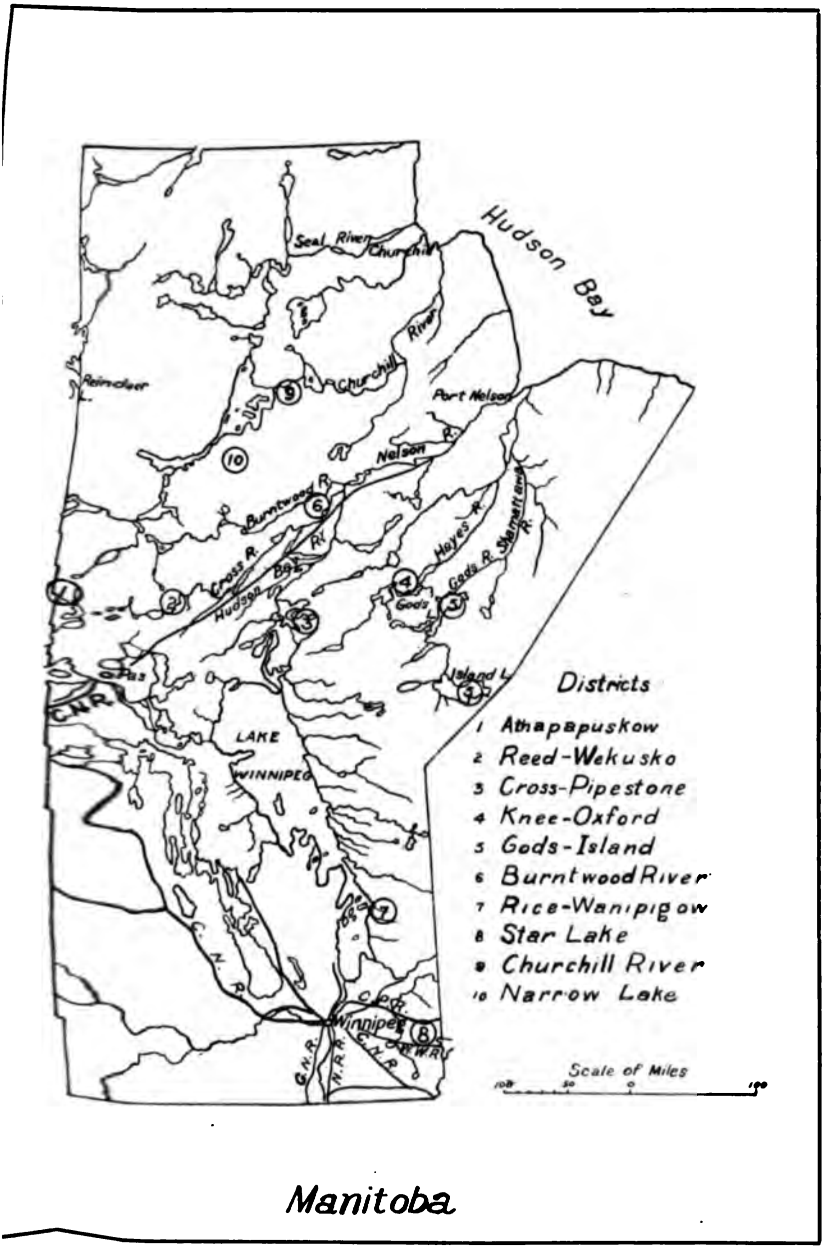

FIGURE 1.—*Map showing certain pre-Cambrian Areas in Manitoba*

areal extent. In parts of the country as much as one-fifth of the surfac is water. This youthful drainage in a country with such low relief is direct result of disorganization by Pleistocene glaciation.

The present topography is largely an inheritance from pre-Ordovicia time and is a result of the stripping off of the Paleozoic sediments whic once covered the region. That the topography is really that of the pre Paleozoic surface is shown by the profile at the base of the Ordovicia Both areas of Paleozoic rocks of the province offer an opportunity for th study of the surface on which the advancing Ordovician sea deposited it sediments. It was a surface of low relief, with minor irregularities muc like the present pre-Cambrian surface. It was also a surface nearly fre from debris, for in most places the basal Ordovician horizon is dolomit resting on fresh pre-Cambrian rocks. Local clastic deposits are found a the base of the Ordovician on the Lower Churchill River,[2] in the vicinit of the Cranberry lakes,[3] where a sandstone occurs, and at some othe places; but these clastic beds are exceptional.

General Character of the pre-Cambrian Rocks

Granite and granite-gneiss form approximately 98 per cent of the rock of the pre-Cambrian belt of Manitoba. Here and there, however, ar areas of volcanic and sedimentary rocks which afford the only means c deciphering the pre-Cambrian history of the province. These areas ar mere remnants which escaped the erosion of pre-Ordovician time. Som of them are synclinal, caught between rising granite masses, and thei limited area shows the great extent of the erosion which stripped an incised the batholiths. These rocks occur in ten main areas. The follow ing table shows the succession of the formations in each area, but it i not meant to suggest that there is any definite correlation of types fro area to area. In neighboring districts similar formations may be ap proximately of the same age, but where areas are separated by long di tances definite correlation seems now to be and may always be impossibl

Description of Areas

Athapapuskow Lake Area[4]

The Athapapuskow Lake area lies 50 miles north of the Saskatchewa River and is part of a larger area extending westward beyond Amis Lake, in the Province of Saskatchewan. The following is the pre-Cam brian succession:

[2] F. J. Alcock: Geol. Surv. Can., Sum. Rept., 1915, p. 135.
[3] J. B. Tyrrell: Geol. Surv. Can., Ann. Rept., vol. xiii, part F, p. 39.
[4] E. L. Bruce: Amisk-Athapapuskow map area. Geol. Surv. Can., Memoir 105.

At	Churchill River	Narrow Lake area	Lake of the Woods and Rainy Lake
	Alcock	Alcock	Lawson
			Diabase dikes
Kamini Granite Hybrid	Pegmatite Granite	Granite	Algoman granite
Upper Missi Lower Missi	Churchill quartzite		Seine series
Cliff La phyry			Laurentian granite
Kisseyn Sedime gneiss Amisk Lava Tuffs ...hists Agglom	Sedimentary schists Green schists	Lamprophyre Porphyry Greenstones and pyroclastics Paraschist Paragneiss	Keewatin volcanics Couchiching sedimentary schists and gneisses

	Kaminis granite.
	Granite-gneiss.
	Hybrid granite rocks.
(Intrusive contact.)	
Upper Missi series	**Arkose.**
	Conglomerate.
(Unconformity (?).)	
Lower Missi series	**Slate.**
	Graywacke.
	Quartzite.
	Conglomerate.
(Unconformity.)	
	Cliff Lake granite-porphyry.
(Intrusive contact.)	
Kisseynew gneisses	**Sedimentary and igneous gneisses and schists.**
Amisk series	**Lavas, tuffs, agglomerates and derived schists.**

The oldest rocks of the region are volcanics, representing ancient surface flows, with fragmental rocks of volcanic origin, ash beds, and agglomerates. Some intrusive rocks closely related to the surface types occur. The surface flows are now massive greenstones that locally retain their original ellipsoidal and amygdaloidal structures. The massive greenstones have suffered severe metamorphism and in thin section are seen to consist of nothing but a felt of secondary minerals. In places intense shearing and squeezing have developed marked schistosity. The greenstone rocks are intruded by dikes of quartz-porphyry, a light gray, fine-grained rock in places showing macroscopic quartz phenocrysts. A complex of gneissic rocks occurring in the northern part of the area is described under the term Kisseynew gneisses. Some of the gneisses are of sedimentary origin, but there are also many sills and bosses of intrusive rocks. The sedimentary members are well bedded, light to dark colored rocks, which consist of quartz, feldspar, biotite, and garnet. The igneous rocks are granite-gneisses, some of them garnetiferous, probably where masses of sediments have been absorbed. A great number of large pegmatite dikes occur with this group. The sedimentary gneiss appears to overlie the Amisk volcanics, but no trace of an unconformity was found between the two, and the relation appears to be a gradual transition from the dominantly igneous rocks of the Amisk group to the dominantly sedimentary rocks of the Kisseynew gneisses. It is possible even that some of the bands of the latter are merely altered representatives of the former. The gneisses are therefore assumed to be merely the upper part of a great formation of which the Amisk volcanics form the lower part.

East of Cliff Lake, rocks of the Amisk volcanic group are intruded by granite-porphyry, a pink-colored rock mottled with pale blue to lavender-colored phenocrysts of quartz. This is regarded as older than the sedimentary series described under the term Missian, on account of the presence in the sediments of grains of peculiar bluish quartz similar to the quartz of the granite-porphyry and of pebbles of granite with striking graphic intergrowths similar to textures displayed by the rocks of the Cliff Lake boss.

The Missian sediments are typically developed on Missi Island, at the northern end of Amisk Lake. They are divided into two groups, described respectively as the Lower and the Upper Missi. The Lower Missi consists of conglomerate, quartzite, slate, graywacke, and carbonate rocks. The greater part of the series consists of a great thickness of quartzite and slate. The slates are extensively drag folded, and consequently their thickness may be much less than it appears.

The lithology of the rocks of the Lower Missi is sufficiently different from those of the Amisk group to justify differentiation from the volcanics, and, moreover, there is structural evidence of an unconformity between the two series. In most places the slates and quartzites dip very steeply or are vertical, and the position of the axes of the folds can be inferred only by interpretation of the minor folds. Along the southern limb of the syncline lying just north of the bay into which Sturgeon Weir River empties the fold has not been so closely compressed. There the slates of the Missi group strike nearly west and dip northward at angles of 30 degrees or less. The general strike of the schistosity of the volcanic rocks in this vicinity is north to northeast. Hence, since the compression, which threw the sediments into close folds, developed a northwesterly trending structure, it is evident that the slates overlie the volcanics unconformably and were deposited after some schistosity had already developed.

The character of the sediments indicates a period of rather unstable conditions, with alternations of well sorted siliceous material now forming quartzites, clayey beds now slates, and less well sorted debris which has consolidated as graywacke. Certain periods were sufficiently undisturbed to produce thin bands of carbonate rocks, but even in these there is a large proportion of detritus. Apparently the period of sedimentation was one of many changes, and all of the rocks belong to shore or near-shore types.

The Upper Missi rocks consist of arkose and conglomerate which in places rest unconformably on the Amisk volcanics. No contact was found with the Lower Missi, but the presence in the conglomerate-arkose of the

Upper Missi of quartzite pebbles similar to the quartzite of the Lower Missi is considered evidence of an unconformity. One boulder of conglomerate was also found in the Upper Missi conglomerate. Along the northern border of the Upper Missi conglomerate-arkose area are bands of hornblende-bearing schistose rocks that apparently belong to the sedimentary series.

The rocks of the Upper Missi group are poorly sorted. They consist principally of a fairly feldspathic arkose now considerably recrystallized. Much of it is conglomeratic, and neither the finer grained arkosic bands nor the coarser conglomeratic bands have great linear extent. In many places conglomerate bands a foot in thickness have a length of only a few feet. A great variety of pebbles are found in these beds. Granite-gneiss, quartzite, and vein quartz with considerable jasper are the most abundant, but fragments of greenstone also occur. Some of the greenstone fragments were apparently schistose before being included in the sediments, showing that a period of folding intervened between the extrusion of the lavas and the formation of the Upper Missi conglomerate. No well sorted rocks nor limestones occur and all the characteristics of the whole Upper Missi group are those of terrestrial sediments laid down by torrential streams under climatic conditions suitable for the maximum of mechanical disintegration.

Granite and granite-gneiss are intrusive into rocks of the Upper Missi series and all the older formations. They are the youngest pre-Cambrian rocks of the region.

REED-WEKUSKO AREA[5]

The Reed-Wekusko area adjoins the Athapapuskow map sheet on the east. The two form a continuous belt extending in an east and west direction for a distance of 130 miles, but the former presents some features distinct from the latter. The pre-Cambrian succession of the Reed-Wekusko area may be tabulated as follows:

Batholithic intrusives................. Granite-gneiss and its differentiates.
(Igneous contact.)
Wekusko group.
  Mica schist....................... Garnet-staurolite and cyanite-bearing varieties.
  Garnet-gneiss.
  Graywacke, arkose, quartzite, conglomerate.
  Slate and phyllite.
  Kiski volcanics.
    Autoclastics and pyroclastics.

[5] F. J. Alcock: The Reed-Wekusko map area, northern Manitoba. Geol. Surv. Can., Memoir 119.

Acid volcanics, including quartz-porphyry, rhyolite, and derived sericitic schists.

Basic volcanics (greenstones), including andesite, basalt, diorite, and derived chlorite, mica and hornblende schists.

The volcanic rocks nowhere occupy large areas in the region, for the most part forming fringes along the lakes. The basic or greenstone varieties are the most abundant, but a zone of dominantly acid rocks occurs along the east coast of Wekusko Lake and is economically important because it contains the larger quartz veins of the area. The rocks consist of flows, tuffs, breccias, and intrusives, with schists derived from these types. In some of the massive greenstone definite evidence of flow origin, such as amygdaloidal and ellipsoidal structure, is observed; in other massive types the rock is coarser-grained and in thin section presents the character of diorite, which may represent either the interior portions of thick flows or intrusives. Some of the flow rocks have the composition of basalts; intermediate types, however, of the composition of andesites and dacites are more common.

The acid volcanic members are light-colored rocks, in places massive, in places sheared into sericite schists. They vary in composition from rhyolite to dacite. Some are porphyritic, with phenocrysts of quartz and feldspar. Acid flow breccias and finely banded, gray tuffs are also associated with the flows.

The sedimentary rocks of the Wekusko group consist of garnet gneisses, mica schists, and bands of arkose and conglomerate. The dominant rock type is a finely banded gneiss varying from light gray to dark gray in color. Nearly everywhere the rock is garnetiferous and in places garnets are very abundant. On the weathered surface, lines of original bedding and cross-bedding may locally be distinguished. In thin section the rock is seen to consist of quartz, orthoclase and plagioclase feldspar, biotite, and muscovite, with accessory iron oxide and apatite. The mica shreds are parallel and the quartz grains are fresh, with interlocking outlines showing that the rock has suffered recrystallization.

The mica gneisses pass by loss of feldspar into mica schists. Of these there are several varieties, depending on the character of the secondary silicates developed in them. Some contain many well crystallized garnets, a few of which reach a diameter of over two inches. In other types staurolite is the characteristic mineral, with crystals from one to four inches in length, which stand out prominently on weathered surfaces. The matrix is a biotite schist containing small red garnets. In certain outcrops small staurolite crystals lie in bands which apparently mark the original bedding planes. In one locality a cyanite-bearing schist is inter-

banded with staurolite and garnet schists. The cyanite crystals stand out in fan-shaped aggregates. Certain bands contain both cyanite and staurolite, others contain staurolite and garnets, still others contain only one of these minerals, and several bands consist of a white muscovite schist with no other secondary silicates developed.

In places narrow bands of the garnet- and staurolite-bearing schists are conglomeratic, containing squeezed pebbles and boulders of quartz, granite, and volcanic rocks. A few wider bands of conglomerate occur in the area, some of which may possibly correspond to the Missian sediments of the Athapapuskow area. The matrix, however, is garnetiferous, and no definite field evidence was found that any of them are infolded sediments unconformably overlying the volcanic and schist rocks. On the other hand, conglomerate is in places definitely interbanded with rhyolite. Hence the whole is regarded as essentially one series.

All these rocks are intruded by granite and pegmatite. In places the secondary silicates in the older rocks appear to be a result of contact, and in others of regional metamorphism. In several places they are abundantly developed near granite stocks and the schistosity of the inclosing rocks follows the contact, but in other places there is no adjacent intrusive, and yet the whole series is intensively metamorphosed. This seems to be regional metamorphism.

Of the intrusive rocks massive granite is more characteristic than the well banded granite-gneisses. Red and light gray are the prevailing colors, although more basic, dark gray types are found locally, especially along the borders of the intrusives. In texture, all phases from coarse to fine-grained are found and porphyritic types locally occur along the borders of stocks. The composition varies from acid granite to diorite. Biotite granite is the most common variety, but hornblende and hornblende-biotite types are also found. Pegmatite, lamprophyre, and aplite dikes and quartz veins occur as late differentiates.

CROSS-PIPESTONE AREA [a]

Pipestone and Cross lakes are expansions of the Nelson River, situated approximately 60 miles north of the northern end of Lake Winnipeg. The pre-Cambrian rocks of the region consist of granite and granite-gneiss intrusive into a complex of sedimentary and volcanic rocks and in turn cut by gabbro and diabase dikes. The granite covers much the greater part of the area, the older rocks being restricted to narrow fringes along the shores of the lakes and to some of the islands.

The volcanic members of the pre-granite complex are dominantly basic

[a] F. J. Alcock: Cross-Pipestone map area, Manitoba. Geol. Surv. Can., Sum. Rept., 1919.

flows, in places showing good ellipsoidal structure. In thin section they are all seen to be highly altered, consisting of a mass of secondary minerals, chiefly light green hornblende, sericite, epidote, and carbonate with iron oxide in varying amounts. The rocks grade into schists, of which the chief varieties are those containing chlorite and hornblende. Hornblende schist is a common phase near the contacts with granitic intrusives and in places it is garnetiferous. An outcrop of a white anorthosite on an island in Pipestone Lake near the mouth of Nelson River consists almost entirely of labradorite. From its association with the greenstone volcanics, it is considered to be a differentiate from them. Other fine-grained, dark rocks with banded structure associated in places with the more massive volcanics are thought to be tuffs. With the massive, dark-colored flow rocks, light-colored acid types occur locally, commonly as parallel bands alternating with the darker-colored varieties. In places they have the appearance of being interbanded flow rocks, and in others they have dike relationships cutting the basic rocks. Thin sections show that they are fine-grained rocks, consisting of quartz and feldspar with phenocrysts of orthoclase, acid plagioclase, and quartz.

The sedimentary rocks of the complex are exposed chiefly between Cross and Pipestone lakes. The succession is from greenstone through finely banded, dark, tuffaceous beds to true sediments which become coarsely conglomeratic. The sediments stand vertically or with steep dips. They are poorly sorted and show great irregularities, both along and across their strike. The conglomerate layers contain boulders of granite, acid and basic volcanic rocks, and vein quartz. The granite and quartz pebbles are well rounded, whereas most of those of volcanic origin are subangular. The series is coarsely cross-bedded in a manner suggestive of torrential river deposits. A band of greenstone 200 feet in thickness lies between two beds of conglomerate.

Two other areas of sediments occur in the region. The rocks of Indian Reservation and adjacent islands are quartzite and sedimentary gneiss with conglomeratic horizons. On the northwest shore of Indian Reservation Island a band of greenstone lies between two beds of conglomeratic garnet gneiss. The lower bed is coarsely conglomeratic, with large boulders of granite which have been squeezed out parallel to the contact with the adjoining granite. The third area consists of a strip of the mainland near the outlet of Cross Lake. The dominant rock type is finely banded gneiss which is nearly everywhere garnetiferous. Locally, certain bands contain rounded pebbles and boulders, for the most part of granite. The beds nearly everywhere are vertical. Locally, a hybrid rock has been produced by lit-par-lit injection of granite along the bedding planes of the sediments.

The series is interpreted as one of conformable sediments interbanded with volcanic rocks.

KNEE-OXFORD LAKES DISTRICT[7]

In the Knee Lake district a complex of volcanic and sedimentary rocks is intruded by stocks and batholiths of granite. The solid rocks are thickly covered by Pleistocene and Recent deposits, and outcrops are neither large nor continuous. Hence the relationships of the different formations must not be considered as unquestionably determined and the succession suggested may require some modification.

Table of pre-Cambrian Formations

Granite.		
(Intrusive contact.)		
Quartz-porphyry dikes.		
(Intrusive contact.)		
Pre-granite complex..........	*Upper part.*	Lavas, tuffs, and volcanic fragmental rocks, with some sediments.
	Lower part.	Conglomerate slate graywacke. Biotite gneiss, etcetera, with some lava flows.

Lithological Characters

Pre-Granite Complex, Lower Part

The lower part of the pre-granite complex is dominantly sedimentary in origin, but volcanic fragmental rocks and some lavas are interbedded with the sediments. The sedimentary beds are heterogeneous in character and seem to be variable from place to place along the strike. The various types include biotite gneiss, garnet gneiss, massive biotite rocks, slate, impure quartzite, and conglomerate. The gneisses and the massive biotite rock are the most commonly exposed, because most resistant. The biotite gneiss is a grayish rock that weathers a dull brownish gray. It is well banded, and weathered surfaces show the banding prominently due to difference in the hardness of the laminations. In places the harder layers are attacked transversely, leaving them merely as rows of conical elevations.

Under the microscope the mica schists are found to consist largely of quartz grains, many of which show distinct rounding. The biotite is arranged in parallel position. Some foils lie between the quartz individuals, but much of it penetrates the quartz and is apparently secondary

[7] E. L. Bruce: Knee-Oxford area. Geol. Surv. Can., Sum. Rept., 1919.

in origin. Some feldspar, both plagioclase and orthoclase, is present and is replaced to an even greater extent than is the quartz. A little green amphibole is present in some sections and some chlorite. Pyrite occurs in most specimens and there is some evidence of the introduction of secondary quartz. In some of the gneiss garnets have developed rather abundantly, and in certain bands mark the original bedding planes. The massive mica rock differs from the gneisses only in the lack of distinct foliation. Under the microscope the biotite shows no parallel orientation. More hornblende is present than in the foliated rocks, a greater proportion of plagioclase to orthoclase, and a somewhat greater variety of minerals, including considerable epidote.

Associated with the gneissic rock are well banded, fine-grained, impure quartzites, fine-grained slates, and a dark green weathering, slaty rock that is in places conglomeratic. There are also thick beds of fragmental rocks which are, at least in part, conglomeratic, but which may also contain pyroclastic fragments. The pebbles consist of rocks of many types, quartz, granite, granite-porphyry, quartzite, and rocks that are very similar to the gneissic rocks and to the greenstones.

The lava flows interbedded with this complex of gneisses and sediments do not show typical ellipsoidal weathering, but massive greenstone bands occur, and it is probably from these that the greenstone fragments in the conglomerates are derived. The lavas are comparatively fresh and vary from andesite to basalt in composition. Some of them are fairly coarse grained and show typical diabasic texture.

Pre-Granite Complex, Upper Part

The rocks of the upper part of the pre-granite complex are lavas and associated volcanic rocks, with some sedimentary members of minor importance. Most of the lavas are now ellipsoidal weathering greenstones which had originally the composition of andesite. There is the usual development of amygdaloidal and autoclastic rocks and some ash beds.

The sedimentary rocks grouped with these are of two types: (1) A chert conglomerate, and (2) iron formation with associated black slate. The conglomerate contains rounded to subangular fragments of chert and greenstone cemented by chert. With the conglomerate occur well banded chert layers, some of which are truncated by later laminations. The iron formation consists of thin laminations of granular quartz and magnetite. Well banded black slate occurs along with the true iron formation and possibly represents a change in character along the strike of the same bed. All of these sedimentary bands are thin.

Quartz-porphyry occurs as dikes cutting the greenstone and seems likely to be a minor intrusive phase of the period of volcanic activity.

The Granite

The surface consolidated rock of the greater part of the area is a fresh massive granite that weathers to a faint pink. It has been found intruding both the lower and the upper members of the pre-granite complex, but has not been found cutting the quartz porphyry. The fresh and unaltered character of the granite is fairly conclusive evidence that it is younger than the sheared and altered quartz porphyry.

Relations of the Sedimentary and Volcanic Groups

Groups of the pre-Granite Complex

It is believed that the dominantly volcanic group of rocks is younger than the dominantly sedimentary group, but that the two are not separated by any unconformity and are a thick, practically continuous series. This conclusion is based on the following facts:

1. The rocks of the sedimentary group in proximity to the volcanic group have dips that vary from 90 to 60 degrees. Where the beds are not vertical the dip is in all cases underneath the greenstone series.
2. The rocks are not overturned, since at one exposure at least the evidence seems conclusive that the top of beds dipping underneath the greenstone is toward the volcanic rock.
3. At one locality there seems to be a gradation from one group to the other.

The top and bottom of the section is determinable in an exposure on the south shore of the lake one and one-half miles west of the trail to Gods Lake. The dip of the beds at that point is 60 degrees north. At the southern part of the section are well banded slates alternating with hard quartzitic layers. Northward there is a flow of andesite 10 feet thick, succeeded by a thick band of fragmental material, conglomeratic or possibly in part tuffaceous. To the north of this is a flow of basic rock of basaltic character which becomes finer in texture toward the north. A few hundred feet northward, across an arm of the lake, is the typical ellipsoidal weathering greenstone of the upper group of the complex. (See figure 2.)

At the contact of the fragmental rock with the andesite flow there are distinct tonguelike projections of the fragmental rock into the andesite. (See figure 3.) This seems to be most satisfactorily explained on the assumption that the surface of the lava flow cracked during cooling and

that the clastic material filled up the crevices formed. Hence the top of the bed lies toward the greenstone. This supposition is corroborated by the gradation in the basic flows from coarse-textured to finer-textured rock from the conglomerate northward.

A gradation from the banded rocks of the lower group to ellipsoidal weathering rocks of the upper group is shown in exposures three miles farther west. At this place the sediments dip northward at an angle of 70 degrees and are succeeded by greenstone. Near the contact the banding in the siliceous slates of the lower group becomes somewhat indistinct and the rocks become the nearly massive biotitic variety. Above these are bands of biotite in elliptical forms, and finally the typical ellipsoidal greenstone. It is suggested that the lava may have been poured out on a still unconsolidated mud into which the ellipsoids sank, squeezing the oozy material into the openings between them. This mud now forms the biotitic margins of the lower ellipsoids.

From these characteristics it seems reasonable to assume that there is in this district an immense sedimentary series with some volcanic rocks intercalated. This series may be largely terrestrial in origin, the conglomerate beds being deposited in torrential streams. Periods of local erosion no doubt occurred, but without any important or widespread hiatus. Later, volcanic activity became more intense and conditions probably changed from land deposition to submarine, so that the upper part of the complex consists of ellipsoidal greenstones with only very minor amounts of clastic material. After the consolidation of these sedimentary and volcanic rocks and their very severe dynamic metamorphism, probably at great depth, batholiths of granite were intruded. Long periods of erosion have now uncovered these batholiths and have removed all but the deeper folds of the pre-granite complex.

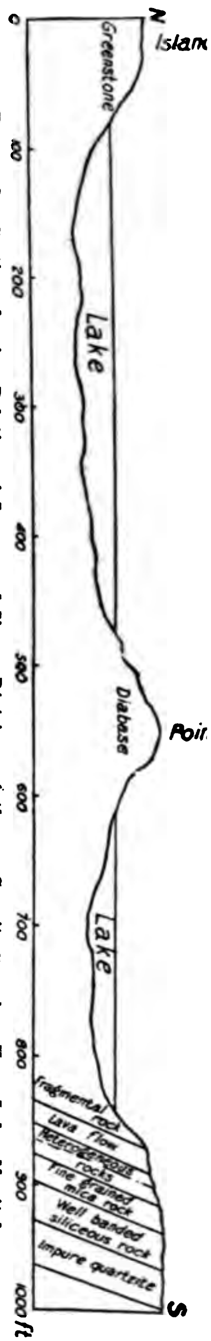

FIGURE 2.—*Section showing Relation of Lower and Upper Divisions of the pre-Granite Complex, Knee Lake, Manitoba*

GODS-ISLAND LAKES AREA[a]

Several isolated areas of rocks similar to those described are found in the region of Gods and Island lakes and on Gods River. This region is drained by Gods River to Shamattawa River and thence into the Hayes. It is the least accessible part of Manitoba and the only geological information available is from hurried reconnaissance surveys. A. G. Cochrane mentions the occurrence on Gods Lake of mica, hornblende and diorite schists, massive diorite, and "compact, dark, greenish-gray diorite with small quartzite pebbles." This is probably a graywacke derived from the dioritic rocks, which has been reconstituted into a rock like the original. Sediments of this kind are found in the Lake Athapapuskow region. No statement is made regarding the relation of these rocks to the granites and gneisses called Laurentian.

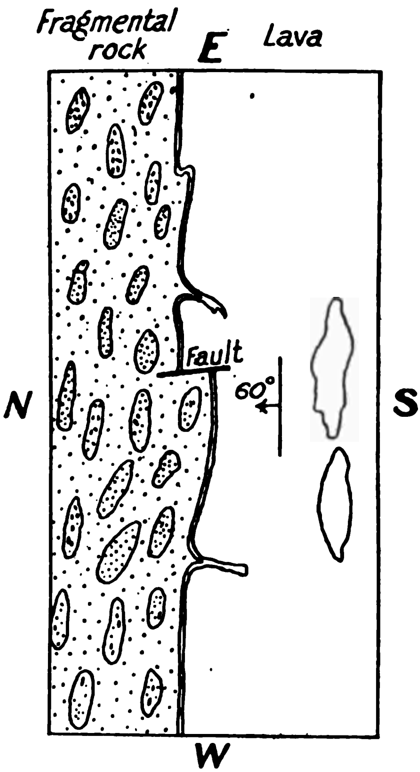

FIGURE 3.—*Diagrammatic Plan of Contact of fragmental Rock and Lava Flow in Section*

Fragments average 6 inches in length

Island Lake is situated south of Gods Lake, near the boundary between Manitoba and Ontario. It is approximately 50 miles long and is said to be full of islands. Cochrane notes "dark gray felsitic schist, glossy calcareous schist, siliceous slate, and felsitic slate of an olive gray color." Steatitic schist, hornblende slates, and schistose conglomerate are also reported, but without any detailed description or statement of the relations of the various types. Serpentine is also reported.

On Gods River is a small area of schistose conglomerate situated about half way between Gods Lake and Shamattawa rivers. It is said to overlie the syenite gneiss and is cut by basic intrusives.

[a] A. G. Cochrane: Geol. Surv. Can., Rept. Prog., 1879, p. 29*e*.

BURNTWOOD RIVER AREA [9]

The Burntwood River area lies about 75 miles north of the Cross Lake area. It is readily reached by a portage route starting at mile 185 on the Hudson Bay Railway. The area shows a complex of volcanic rocks and gneisses surrounding Pipe Lake, a body of water about 10 miles in length, which drained Manasan River into Burntwood River. The belt of greenstone extends northward to the Burntwood and southward west of Pipe Lake.

The rocks of the area consist of granite, garnetiferous gneisses, greenstones, and green schists. The greenstone belt is very narrow, forming the islands of Pipe Lake and a discontinuous fringe on either side of the lake. Associated with the more massive greenstone rocks are a few local areas of banded rocks which are believed to be tuffs. The characteristic contact phase where the granite intrudes the volcanics is a black, glistening hornblende schist. In the granite areas near the contact with the greenstone belt are a number of small, isolated areas of hornblende schist representing engulfed masses and roof pendants.

Immediately northwest of Pipe Lake is a ridge composed of finely banded, dark gray gneiss which has the appearance of an altered sediment. It stands on edge; its position between the greenstone band and the granite suggests that it underlies the volcanic rocks.

Along the contact with the greenstone belt the granite is gneissoid and sheared. On the east side of the lake the banding is highly contorted. This zone grades out into massive granite. On the west side of the lake the granite along the contact with the greenstone is highly sheared with schistosity developed parallel to the contact.

The granite and granite-gneiss rocks of the area include a number of types which may possibly represent more than one period of intrusion. Along the Burntwood River a garnetiferous gneiss is very abundantly developed. Though locally banded, its general texture and appearance is quite different from the finely banded garnetiferous gneisses of the other areas, which have been described as altered clastic rocks. It is probable that the presence of the garnets means the absorption of engulfed sediments. A number of pegmatite dikes were found in the areas in which garnets were similarly developed. Over much of the area the granite is massive, with but little gneissic structure.

[9] F. J. Alcock: Ospwagan Lake-Burntwood River area, northern Manitoba. Geol. Surv. Can., Sum. Rept., 1920.

RICE LAKE-WANIPIGOW RIVER AREA [10]

The Rice-Wanipigow area lies in the southeastern part of the province; it has attracted considerable attention on account of the large number of gold prospects which have been staked in the area. Geological work was performed in the area in 1912 by Moore, in 1916 by Dresser, in 1917 by Marshall, and by Colony, De Lury, and McCann in 1920.

The oldest rocks are lava flows, which in places show well marked ellipsoidal structure. They have been intruded by quartz-porphyry, quartz-feldspar porphyry, and feldspar-porphyry. All these rocks are intruded by hornblende granite, which is in turn intruded by norite.[11] Near the granite the volcanic rocks have been altered into glistening, black hornblende-schist. Except at the contact and in local areas, the rocks are massive.

Schists and gneisses which are considered of sedimentary origin have been observed at a number of places in the area. They are of fine texture and predominantly of a red color. In thin section they are found to consist of quartz, fresh orthoclase and acid plagioclase, brown biotite, muscovite, and garnet. A band of conglomerate 30 feet thick outcrops on Slate Lake. It consists of a gray-green matrix with pebbles of greenstone, quartz, jasper, and porphyry fragments. It is highly metamorphosed. According to Marshall, it rests unconformably on what appears to be a feldspar porphyry. Other outcrops of conglomerate are described by Moore. The sedimentary rocks are grouped together by him under the term Wanipigow series, placed above the volcanic rocks which he correlates with the Keewatin. The volcanics and sediments are all intruded by granite, granite-gneiss, and pegmatite.

STAR LAKE AREA

The Star Lake area lies in the extreme southeastern corner of Manitoba, immediately south of the Canadian Pacific Railway.

No detailed geological mapping or study has been made, but the area has been visited by Wallace and De Lury for the Public Utilities Commission of Manitoba, and by Marshall and Bruce, of the Geological Survey, who have reported on the claims staked for gold, molybdenite, scheelite, and platinum.

The oldest rocks of the region are ellipsoidal lavas and derived schists, with which are associated some areas of sedimentary rocks. The latter include conglomerate which contains pebbles of the volcanic rocks as well

[10] E. S. Moore: Geol. Surv. Can., Sum. Rept., 1912, p. 262.
[11] R. J. Colony: Bull. Can. Inst. Min. and Met., no. 103, November, 1920, p. 862.

as fragments of other types. The volcanic and sedimentary rocks occ as a narrow band between great areas of red granite which is intrusi into them. South of Star Lake an isolated boss of a granitic rock i trudes both the conglomerate and the volcanics. It shows a considerab degree of variation. In places it is a hornblende syenite, in others binary granite.

CHURCHILL RIVER AREAS[12]

Though the Churchill River flows throughout most of its course over granite and granite-gneiss, a few local areas of schists and sediments are found. One of the largest of these bands is situated about 10 miles east of the outlet of Southern Indian Lake. The dominant rock type is a dark gray, sheared quartzite containing considerable quantities of sericite. It stands at a high angle and is cut by gray granite and dikes of pegmatite. A few small patches of hornblende and chlorite schists occur along the river; they are associated with finely banded gneisses traversed by pegmatite dikes.

The granites and gneisses which intrude these rocks consist of both gray and red varieties and include both biotite and hornblende-bearing types. One variety of red granite is porphyritic and appears to be younger than the regional gneiss.

In the vicinity of Fort Churchill is a sedimentary formation consisting of arkose and quartzite. The beds stand at a high angle and are cut everywhere by small quartz veins. Hence, though no contact with the granite was observed, it is concluded that it is older than the granite. It is, however, different lithologically from the pre-granite schists, is much less highly metamorphosed, and has accordingly not been classed with them. It is possible that it occupies a position similar to that of the Missi series of the Lake Athapapuskow district.

NARROW LAKE AREA[13]

The Narrow Lake area lies on a canoe route between Nelson House and Southern Indian Lake, in approximate latitude 59° and longitude 99° west. It is a small area, with a length of but eight miles, situated immediately west of Narrow Lake, an expansion of the Rat River.

The rocks of the area consist of a narrow belt of sediments and volcanics intruded on either side by massive, red granite. The pre-granite series pinches out to the northeast; to the southwest it also narrows, and

[12] F. J. Alcock: Geol. Surv. Can., Sum. Rept., 1915, p. 133.
[13] F. J. Alcock: The Rat River route from Threepoint Lake to Southern Indian Lake. Geol. Surv. Can., Sum. Rept., 1920.

then disappears under a heavy overburden of clay. The succession is as follows:

Granite.
(Intrusive contact.)
Volcanic flows and pyroclastics.
Mica schist.
Paragneiss.

The oldest rock is a finely banded, gray gneiss which in places carries garnets. In its upper part it is interbanded with a black mica schist. In places the contrast between the gray or reddish gray bands and the black schist bands is very marked. The bands vary in width from less than an inch to over a foot. Above the interbanded zone the series consists of black banded mica schist. The whole was once clearly a series of clastic and shaly beds which have been highly metamorphosed.

The volcanic rocks consist of andesitic greenstones which in places show flow structure. Certain parts are composed of large oval masses composed of the same material as the flows and considered to be pyroclastics. Dikes of porphyry lamprophyre were found cutting the volcanics.

Structurally, the schists and paragneisses everywhere dip underneath the greenstone belt. The dips average around 45 degrees. The series forms a monocline cut off on either side by intrusive granite.

LAKE OF THE WOODS AND RAINY LAKE AREAS[14]

The Lake of the Woods and Rainy Lake region is one of the classic areas of pre-Cambrian geology, and the succession determined there has played an important part in pre-Cambrian nomenclature. It was there that the term Keewatin was introduced by Lawson, and the intrusive relationship of the Laurentian granite to the Keewatin volcanics was shown by him in 1885. In 1911 Lawson restudied the Rainy Lake region. The pre-Cambrian succession, according to his latest work, is as follows:

Keweenawan	**Diabase dikes.**
Algoman	**Porphyroid gneiss, banded and streaked gneiss, granite and granite-gneiss, syenite gneiss, basic phase of syenite.**
Huronian.	
Seine series (Upper Huronian)	**Lamprophyre rocks.**
	Quartzite and slate.
	Conglomerate.
Laurentian	**Granite and granite-gneiss.**

[14] A. C. Lawson: The Archean geology of Rainy Lake restudied. Geol. Surv. Can., Memoir 40.

Keewatin	**Anorthosite.**
	Hornblende gabbro.
	Limestone.
	Greenstone, greenstone schist, chlorite schist, hornblende schist, felsite, sericite schist, ash beds, agglomerate, siliceous slates and schists, chert, mica schist.
Couchiching	**Mica schist, paragneiss, phyllite.**

The Couchiching rocks consist of a group of mica schists, feldspathic mica schists, and finely banded gneisses. According to Lawson, they uniformly underlie the volcanic rocks termed Keewatin. The Keewatin rocks comprise: "(1) fine-grained greenstones showing frequently ellipsoidal or amygdaloidal structure, or both; (2) coarser-textured greenstones showing neither ellipsoidal nor amygdaloidal structures; (3) greenstone schists of varying degrees of schistosity; (4) rather massive chlorite schists; (5) evenly fissile chlorite schists; (6) irregularly cleaved chlorite schists; (7) black, glistening hornblende schists, usually on the periphery of the Keewatin belts where they come in contact with granitic intrusions; (8) gray felsites, sometimes amygdaloidal; (9) sericitic schists; (10) various stratified grayish green schists, probably ash beds; (11) agglomerates; (12) gray siliceous slates and schist; (13) banded cherts; (14) mica schist; (15) limestone."

The Keewatin rocks consist of altered volcanics, including flows, tuffs, agglomerates with minor amounts of intrusives and sediments. A medium to coarse grained biotite granite, which is termed "Laurentian," intrudes both the Keewatin and Couchiching rocks.

The Seine series consists of a great thickness of conglomerate grading upward into quartzite and slaty schists. It contains debris derived from the waste of the Keewatin rocks, but most of its boulders are granite, with lesser amounts of greenstone, quartz-porphyry, and chert. Near Mine Center the Seine series rests unconformably on the granite. Where it rests on the granite, it is composed of detritus which is nearly all derived from the underlying granite, and where it rests on Keewatin it is nearly entirely derived from rocks of that series. It is considered by Lawson to be a subaerial formation, representing a gravelly floodplain rather than the beach of a transgressing sea.

The Seine series is intruded by mica-syenite gneiss, to which the term Algoman is applied. Other areas of massive granite and granite-gneiss are believed to belong to the same general period of intrusion as the syenite.

The youngest pre-Cambrian rocks are dikes of diabase which are referred to the Keweenawan.

The feature emphasized by Lawson in his work in this area is that of two widely separated periods of plutonic activity giving rise to batholiths of granites, to which the terms Laurentian and Algoman are applied.

Comparison of the Areas

The problem of correlating areas of pre-Cambrian rocks which are separated by wide intervening stretches of granite is one of the most difficult tasks in geology. At best, all that can be done is to ascertain the most probable correlations from a study of lithology, succession, degree of metamorphism, structure and relationship to intrusives. In Manitoba the most definite feature is the regional granite, which, aside from certain dike rocks, appears to be the youngest pre-Cambrian rock of the province Wherever the relations of the granite to the other pre-Cambrian rocks have been established, the granite has always been shown to be intrusive. This gives us our chief factor in comparing the various areas. It is, of course, possible that the granites of the different areas may be of different ages, or even that granites of more than one age may be represented in the same area, but as yet no proof of this has been obtained. That older granites did exist is shown by the presence of granite boulders in conglomerates which are intruded by the regional granite. At no place in Manitoba, however, have pre-Cambrian sediments as yet been found resting unconformably on granite.

The granite locally presents considerable variation. Such variation is, however, to be expected by differentiation and by the assimilation of engulfed fragments of the intruded rocks. Differences due to these causes have been recognized at a number of places. There are also banded gneisses which have the appearance of being older than the fresh-looking granite, but many of these can be shown to be sediments injected "lit-par-lit" by granite. The only proper basis for the determination of the age of an intrusive is its relation to sedimentary formations, and even this becomes certain only where the sediments can be definitely correlated. It is considered, therefore, advisable to avoid the use of such terms as Algoman and Laurentian in connection with the granites of Manitoba.

Though the exact correlation of the pre-granite complexes of sediments and volcanics in various districts or the correlation even of similar lithological parts of it seems to be inadvisable, nevertheless the pre-granite rocks in a large way exhibit a great deal of similarity throughout the various areas of the province. The lithology is very uniform. The same

types of volcanic rocks appear in most of the areas and in many of them somewhat similar sedimentary formations occur. The resemblances which are displayed by the types from the various areas are due to two causes: First, original similarity, and, secondly, induced similarity, due to metamorphism under similar conditions. Contact and regional metamorphism produce schists and gneisses which may resemble each other very much and yet the similarity may have no age significance. Under extreme conditions, metamorphic processes may even produce from dissimilar original rocks similar derivatives. In spite of these facts, there are, however, certain characteristics of the sedimentary complex from which its original nature can be inferred. The chief of these is the dominance of unassorted clastic sediments. Limestone is entirely lacking. Shale, the predominant rock of a normal marine series, is represented only by a relatively small amount of slate and by the garnet, staurolite- and cyanite-bearing mica schists, analyses of which show a proportion of the oxides such as is characteristic of shale. The dominant sediments, however, in all the areas are paragneisses and arkosic quartzites with conglomeratic bands.

The rock succession also presents features which serve as a basis of comparison. In nearly all the areas the oldest rocks are greenstones associated with more acid volcanics and interbanded with sediments. Conformably overlying these rocks are sedimentary members with interbanded volcanics. This is the succession as worked out in the Cross Lake area and the Reed-Wekusko area and is apparently the succession in the Rice-Wanipigow and Star Lake areas. In the Knee-Oxford Lake area there is a reversal of conditions, with a lower division, consisting dominantly of sediments with interbanded volcanics and an upper division of dominant volcanics with subordinate amounts of sediments. The rock types, however, are much alike in all the areas. In two areas, the Athapapuskow and Churchill River, there are pre-Cambrian series which are apparently younger than the main pre-granitic complex. The Missi series and the Churchill quartzite may represent equivalent series older than the regional granite, but younger than the volcanic-sedimentary complex. They are, however, both of local extent and are lithologically dissimilar, both to each other and to the pre-granite complex of the other areas.

Origin of the pre-Granite Complex

In considering the probable origin of the pre-granite complex the following facts concerning it should be noted:

DISTRIBUTION

Patches of similar rocks with similar structural relationships extend across the whole of the northern part of the Province of Manitoba, a distance of over 300 miles east and west. Similar rocks, with apparently similar relations, are also found in Ontario—the Churchill River area, in the northern part of Manitoba, and the Rice-Wanipigow and Star Lake areas, in the southern part of the province.

LITHOLOGY

The main facts concerning the lithology of the series have already been mentioned, namely, the dominant clastic character of the sediments and the presence of interbanded volcanics.

Most of the sediments are arkosic in character; for, although many of the gneisses are thoroughly recrystallized and their feldspar content is largely secondary in origin, nevertheless the proportions of the feldspars, quartz, and micas show that the original rock must have contained considerable feldspar.

SUCCESSION

The general succession has also been referred to. In the clastic rocks recurrent horizons of conglomerate are common. There is also an absence of any definite succession of conglomerate, sandstone, and shale, as might be expected under marine conditions with an advancing or retreating shoreline.

THICKNESS

There is great variation in thickness in different localities. Locally, there is evidence that some of the sedimentary gneisses attain a thickness of several thousand feet.

BEDDING

In places where the rocks have been less highly altered, lines of bedding can be determined by variations in color or texture. In the conglomerate, bedding can in most exposures be determined by coarse and fine bands; in some of the fine-grained gneisses, by the color banding; in some of the mica schists, by crystals of secondary silicates, such as garnet, staurolite, and cyanite, which stand out in rows and fairly certainly mark bedding planes. In much of the series, however, it is difficult to ascertain absolutely the original structure.

The conglomeratic bands in the gneisses offer some suggestive features. Most of them are local and irregular; some can be traced for a considerable distance along the strike; others can be followed for only a few hun-

dred feet. The matrix is commonly garnetiferous and is exactly like the sedimentary gneisses which contain no boulders or pebbles. The fragments for the most part are well rounded, but in places they are squeezed and elongated parallel to granite contacts. Only locally have garnets been developed in them. No evidence has been found that any of the pebbles or boulders consist of rock which had been rendered schistose before its erosion and deposition in the sediment. The boulders consist of granite, porphyry, acid and basic volcanics, and vein quartz. The granite and quartz pebbles are usually the better rounded, suggesting longer transportation. In places pebbles of volcanics are subangular, suggesting that they had a local origin. There is a lack of sorting, with large and small fragments intermingled and with great variations in the amount of the matrix associated with the boulders.

CROSS-BEDDING

On the weathered surface of many of the gneisses cross-bedding is well shown, and in places it is easily possible to determine by this means the top and bottom of the beds. Locally, as in the Cross Lake area, cross-bedding on a large scale, suggestive of torrential deposits, is excellently displayed. On an island in Cross Lake the width of a cross-bedded horizon between the parallel beds of the main structure is nine feet. The oblique strata in this bed also show alternating coarse and fine layers with conglomeratic bands up to 14 inches in width and finer-grained bands up to 16 inches in width.

CONCLUSION

Summarized briefly, the pre-granite complex is dominantly clastic, with great variations in thickness and in the order of succession of the various lithological elements. A large part of the sediments are feldspathic and only a small part consist of well sorted, argillaceous and quartzose types. In addition, there are numerous conglomerate horizons. Both conglomeratic and arkosic bands show cross-bedding on a large scale. In the igneous rocks of the complex, ellipsoidal structure is common.

It is concluded from these facts that the complex is chiefly of terrestrial origin—in part deposited as outwash fans, in part as deltas, along the continental margin. The lavas were apparently poured out under water during periods of submergence or in the part of the deltas which were below sealevel. The granite pebbles in the conglomerates of this ancient series may have been derived from early granites which were intruded into rocks, of which no record is left—rocks which have been

completely removed by erosion or have been entirely absorbed by igneous intrusions. An alternative hypothesis is that these granite pebbles have come from an original granitic earth's crust.[15]

Summary of geological History

The earliest events of which we have any geological record in the Province of Manitoba are the extrusion and consolidation of successive floods of lava. In some districts the volcanic periods were preceded by periods of terrestrial sedimentation; in others, sediments were interbedded with the volcanics, and in other areas these early periods of sedimentation continued long after the extrusion of lavas had ceased. In places, the volcanic rocks accumulated to great thicknesses; in other places the sediments dominated.

After the close of the early period or periods of volcanic activity and terrestrial sedimentation and after long periods of induration and metamorphism, these early rocks were intruded by granite batholiths. Deep erosion followed and was succeeded by the deposition of later sediments, such as the Missi series of the Athapapuskow district and the Churchill quartzites, and perhaps certain conglomerates in other areas where the relationships have not been absolutely ascertained. These deposits, however, were all local, probably were not contemporaneous, and deposits found at one locality no doubt correspond to a period of erosion at another locality.

Then followed a period or periods of mountain-building in which all these rocks were folded and intruded by batholiths of granite. The older rocks were locally sheared into schists, were highly altered near their contacts with the intrusive granite, and were faulted and closely folded, so that today they nearly everywhere stand at a high angle.

A long erosion era followed the periods of folding and faulting and subaerial processes wore down the mountains to their granite cores. The surface of the country passed from youthful topography through maturity to old age, and before Ordovician time erosion had proceeded so far that only remnants of the older rocks which once covered the entire region were left, either as synclinal areas, which required a greater amount of down-cutting to reach them, or on divides where erosion was less intense. It was over this peneplaned surface that the Paleozoic sea advanced.

[15] Barrell: Origin of the earth.

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WINDROW FORMATION; AN UPLAND GRAVEL FORMATION OF THE DRIFTLESS AND ADJACENT AREAS OF THE UPPER MISSISSIPPI VALLEY[1]

BY F. T. THWAITES AND W. H. TWENHOFEL

(Presented orally before the Society December 30, 1919)

CONTENTS

[1] Manuscript received by the Secretary of the Society October 7, 1920.

Introduction

At widely separated points on the higher uplands of the Driftless and adjacent areas of Wisconsin, Iowa, and Minnesota, there occur conglomerates and gravels with associated limonite, clay, and sandstone.

The interest of the writers was drawn to these gravels while they were engaged in the study of the geology of the Tomah and Sparta quadrangles, in western Wisconsin. As the problem of their origin could not be solved within the limits of that area, the study has been extended over a wider field and the available literature has been examined for descriptions of similar formations in adjacent States. These studies have led to the assembling of a considerable amount of information and to conclusions relating to the origin and age of the deposits.

As these deposits merit a name, it is proposed to call them the Windrow formation, the name being selected because of an excellent exposure on the top of Windrow Bluff, near Tomah, Wisconsin.

Description of the Windrow Formation

The Windrow formation consists of quartz and chert pebbles in a matrix of quartz sand and brown iron oxide, iron oxide cemented sandstone, concretionary limonite, and at some localities blue and white sticky clay. In many places only pebbles are present, as the matrix has weathered away.

The pebbles are mainly quartz and chert. Those of quartz are universally well polished and rounded to spherical and elliptical shapes. The chert pebbles are also well polished, but are mainly of subangular shapes. Most of the pebbles are small; examples of greater than an inch in diameter are rare, although a few chert boulders up to a foot in diameter have been observed. These are not rounded or polished. The relative abundance of chert and quartz varies widely. At an occurrence southeast of Sparta, Wisconsin, a count gave 50 per cent chert, 45 per cent yellow and milky quartz, and 5 per cent pink quartz. At a closely adjacent locality it was found that 75 per cent consists of yellow and milky quartz, 24 per cent of black, gray, and brown chert, and 1 per cent of pink quartz, with an occasional pebble of dolomite. The quartz pebbles vary considerably in shades of color and are utterly unlike any material found in the Paleozoic rocks of the region of their occurrence. They closely resemble the vein quartzes of the pre-Cambrian rocks to the north and northeast and it is probable that such is their source.

Fossils are rather common in the chert pebbles. Not uncommonly they are well preserved and in a few instances a fossil makes an entire pebble

The specimens for the most part are considerably worn, but a few have been collected which show scarcely any wear.

At a number of localities the pebbles are cemented into a conglomerate by manganiferous limonite, and at Waukon, Iowa, the limonite is suffi-

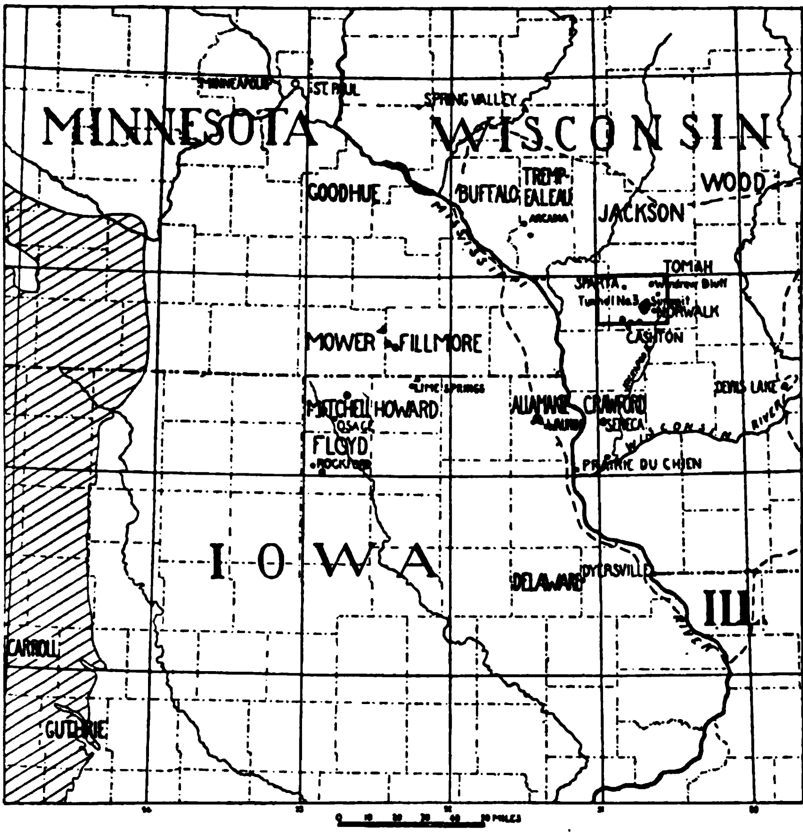

Figure 1.—*Map of parts of Iowa, Illinois, Wisconsin, and Minnesota, showing Distribution of the Windrow Formation*

Sparta-Tomah quadrangles shown by heavy black line. Windrow gravels shown by black spots. Cretaceous areas shown by cross-lining. Distribution of the gravels suggests that they were deposited by streams which flowed southwest into the Cretaceous sea. Boundary of driftless area shown by dashed line.

ciently free from pebbles to be mined for iron ore. The sands which constitute a part of the deposit are mainly coarse grained, poorly assorted, and imperfectly rounded. Wherever bedding has been observed, it is rude and imperfect. Current ripple-marks were seen at one locality.

Occurrences

WISCONSIN

The first known occurrence of the Windrow formation in Wisconsin is that near Seneca, Crawford County (northwest ¼, section 10, township 9, range 5 west), where it caps a hill at an elevation of about 1,350 feet. This outcrop was discovered by Strong and later described by Chamberlin and Salisbury (25, 9). Conglomerate of small quartz pebbles in a matrix of sandy manganiferous limonite covers about an acre of ground, while loose gravel is found over a more extended area. An old shaft, now fallen in, is stated by Chamberlin and Salisbury (9) to have shown that the conglomerate extends into a crevice in the Trenton limestone to a depth of 65 feet from the surface. They also state that the average depth of the deposit is from 5 to 6 feet.

The best known occurrence of the Windrow formation in Wisconsin is on the top of the East Bluff, at Devils Lake (northeast ¼, southeast ¼, section 24, township 11, range 6 east), where loose gravel is found at an elevation of about 1,440 feet overlying the polished and water-worn surface of the Huronian quartzite.[2] Descriptions of this deposit have been published by Irving, Chamberlin, Salisbury, and Alden (13, 8*a*, 14, 21, 1). Salisbury states that a well disclosed a thickness of 16 feet of gravel at a point back from the edge of the bluff, but a pit dug by Alden and Thwaites by the side of the well indicated that the predominant material at that point is deoxidized loess and residuum from Paleozoic limestones and conglomerates. No true gravel was discovered in the excavation. A most striking feature at Devils Lake is the occurrence of several well developed pot-holes in the quartzite. Chert pebbles collected near by show percussion marks similar to those formed in the flint pebbles used in ball mills, and it is suggested that these were made in the formation of the pot-holes. The pot-holes are in no way related to glaciation, as this locality is, beyond reasonable doubt, in the Driftless Area.

The type locality of the formation here discussed is on Windrow Bluff, an outlier of the Oneota escarpment between Tomah and Sparta, on the divide between Lemonweir and La Crosse rivers (northeast ¼, northwest ¼, section 10, township 17, range 2 west). This occurrence was discovered by the senior author and Prof. Lawrence Martin in 1916. A small ledge exposes limonite-cemented conglomerate and ferruginous sandstone which rest on the Madison (?) and Jordan sandstones of the uppermost Cambrian. The pebbles are the same as elsewhere, but a few

[2] This elevation is based on spirit-leveling by engineering students and on barometric observations by R. D. Irving (14). The U. S. Geological Survey map is incorrect.

subangular boulders of Oneota chert are present, one of them a foot in diameter. Bedding is very poorly indicated. The elevation is 1,400 feet.

Two of the most accessible of the Wisconsin occurrences are on the highway just above Tunnel Number 3, on the Chicago and Northwestern Railway, between Sparta and Norwalk (northwest 1/4, southwest 1/4, section 18, township 16, range 2 west), and on the hill near by, just south of the station of Summit, at the eastern portal of the tunnel (southwest 1/4, southwest 1/4, section 17, township 16, range 2 west). At these places the formation consists of much weathered and broken down conglomerate with a sandstone matrix, yellow and red stratified sandstone, and powdery and botryoidal limonite. The thickness appears to be from 10 to 20 feet. The bedding is not well defined. A loose slab showed current ripple-marks. The elevation of these localities is between 1,360 and 1,380 feet.

Loose pebbles, possibly lowered by weathering, are extremely abundant near Pine Hollow Church, about a mile north of Cashton (northeast 1/4, section 29, township 15, range 3 west). The elevation is about 1,310 feet. The material rests on the Oneota dolomite and possibly in part on the Saint Peter sandstone.

Other places in the Sparta and Tomah quadrangles where pebbles or rock of the Windrow formation are definitely known are listed below. In the preparation of this list all doubtful occurrences of one or two pebbles have not been given, since such may represent material transported by human agency, either attached to mud on the wheels of vehicles or carried as curiosities or "lucky stones." At all of these places the underlying rock is the Oneota dolomite:

	Elevation, feet
Township 17, range 2 west:	
North 1/2, section 27	1,400
Township 16, range 2 west:	
East 1/4 post, section 12	1,440
Southwest 1/4, northwest 1/4, section 19	1,400
Northeast 1/4, southwest 1/4, section 20	1,300
Township 16, range 3 west:	
Northwest 1/4, section 23	1,400
East 1/4 post, section 24	1,380
South 1/2, section 36	1,400
Township 15, range 3 west:	
South 1/4 post, section 20	1,360
South 1/4 post, section 22	1,360
Township 15, range 4 west:	
North 1/4 post, section 22	1,334
Center, section 23	1,360

Float gravel is found in the road in southeast ¼, southeast ¼, section 12, township 7, range 5 west, about 12 miles northeast of Prairie du Chien. The pebbles are quartz and local chert; they are well rounded and range up to an inch in diameter. The elevation, as measured by aneroid barometer, is 975 feet. The bedrock is the Saint Peter sandstone, which contains some chert conglomerate.

Float pebbles of water-worn quartz and black chert are abundant in the early Pleistocene terrace gravels of Trempealeau and Jackson counties. The chert pebbles carry fossils, of which all so far discovered have been too poorly preserved to be identified. The only place where any quartz pebbles have been found in these counties on the Oneota upland is south of Arcadia, in section 16, township 20, range 9 west, at an elevation of about 1,200 feet.

The bluffs of Buffalo County are covered by water-worn pebbles of quartz, jasper, chert, and quartzite. Some of the quartz pebbles are several inches in length and some of the quartzites reach 15 inches in diameter. The quartz pebbles are not so well rounded and polished as are those typical of the Windrow formation. The cherts are mainly gray or bright red; few are black. The jasper is mainly of the bright red oolitic type. The quartzites can be divided into two types, (*a*) dark red or purple vitreous quartzite, which is unquestionably not local, and (*b*) much less cemented pink and gray quartzitic sandstone, which may be local. The first type occurs as rounded stones, the second mainly in subangular forms which average considerably larger than the water-worn pebbles. The bedrock in this region is the Saint Peter sandstone and the Oneota dolomite. No rock like the pink quartzites has been seen in place in the Saint Peter, but many ledges resemble the gray type. On the other hand, chert pebbles from the Oneota are rare. The elevation ranges from 1,200 to 1,250 feet. The correlation of these deposits with the Windrow formation is uncertain.

It is probable that there are many localities of the Windrow formation in Wisconsin that have not yet been discovered, since many are probably concealed by the covering of loess. None of the many geologists who have examined the region south of the Wisconsin River have reported any quartz pebbles on the hilltops over that region, so that it is probable that none exist.

There are limonite occurrences in western Wisconsin which do not belong to this formation. The great majority of the known iron ore deposits of the Driftless Area described by Strong (25) are clearly altered sulphides and are not at all like the concretionary, manganiferous limonite of the Windrow formation. The brown ore deposit at Spring Valley

described by Allen (2) is stated by Professor Steidtmann[3] to contain no quartz or chert pebbles, and therefore can not be definitely correlated with this formation.

IOWA

The best known occurrence of the Windrow formation in Iowa is near Waukon, Allamakee County, where it caps an elevation of about 1,360 feet known as Iron Hill (sections 17 and 20, township 98, range 5 west). This occurrence has been described by Orr (18), Calvin (6), Beyer (5), and Howell (12) and was visited by the senior author in 1919. The deposit consists of concretionary, bouldery, hydrous, manganiferous iron oxide covering several hundred acres. It has been carefully explored for iron ore by the Missouri Iron Company and a great deal of development has been done, so that conditions for study are excellent. Parts of the deposit show much sandstone and iron-cemented conglomerate with quartz and black chert pebbles like those in Wisconsin. The main part of the ore body is fairly free from pebbles and has a maximum thickness of about 135 feet. It is separated from the underlying Galena dolomite by a foot or two of residual red clay. Large dolomite boulders and silicified and limonitized fossils occur at some points in the limonite. The minerals present include limonite (the most abundant), turgite, gothite (?), wad, various manganese oxides, and hyalite. Analyses show the following variations in composition (5, 12):

	Per cent
Iron	6.77 to 66.92
Phosphorus	0.072 to 1.87
Manganese	0.33 to 1.02
Silica	3.92 to 60.25
Alumina	3.57 to 18.08

Calvin (6) mentions two other deposits in the same county, one (southeast ¼, section 27, township 98, range 5 west) at an elevation of about 1,200 feet and the other (northwest corner section 6, township 97, range 4 west) at about 1,100 feet.

Alden (1) describes a locality "a few miles southeast of Rockford, Floyd County," as "1 foot to 9 feet of soft buff sandstone (in places loose sand) set full of small, rounded, highly polished fossiliferous black chert and white quartz pebbles." This deposit caps low mounds at an elevation of not over 1,100 feet and rests on the Devonian.

The same author describes "similar sand and gravel . . . about 8 miles northeast of Osage, Mitchell County" (southwest ¼, section 15, township 99, range 16 west). Calvin also mentions this deposit (8) and

[3] Edward Steidtmann: Personal communication.

a better exposure a few rods north of the west end of the bridge at Mitchell (4 miles northwest of Osage). The latter locality was visited by the senior author in 1920. The material is exactly like that at Wa[illegible] and in Wisconsin—concretionary brown and yellow limonite, in large part set full of quartz and black and gray chert pebbles. The pebbles have a maximum diameter of three-quarters of an inch. There is also much sand associated with them. The deposit fills an erosion channel in the underlying Devonian limestone. The elevation at both the Mitchell County outcrops is about 1,200 feet.

McGee (16) describes "a conglomerate of rounded quartz pebbles imbedded in a matrix of impure limonite" in the northeast ¼, section 11, township 100, range 12 west, four miles northeast of Lime Springs, Howard County. This formation is said to be present on several hilltops. The bedrock is the Devonian limestone and the elevation is about 1,200 feet.

Bain describes sandstones and conglomerates in Guthrie and Carroll counties which rest unconformably on the "Coal Measures." The sandstones are soft, of yellow and red colors, and much cross-bedded (3, 4, 19). In them are a few thin layers of blue and white plastic clay. The conglomerates carry "small, smooth and well rounded pebbles of white and pink quartz and black chert." The chert pebbles contain Silurian and possibly Devonian fossils. A few poorly preserved fossil leaves of Mesozoic aspect have been collected from the sandstones, while fragments of similar sandstones containing Cretaceous fossils have been found in the glacial drift (4). The senior writer visited the Guthrie County exposures in 1920. Road grading has made many more opportunities to study the deposits than were formerly available. The base of the formation is well exposed in section 24, township 80, range 31 west. Just west of the bridge over Racoon River 6 feet of gravel rests unconformably on about 11 feet of Coal Measures shale. The pebbles are small and consist of white and pink quartz and gray, yellow, and black chert. The matrix is a coarse yellow sand. Parts of the deposit are cemented by brown limonite which is distinct from the occasional iron concretions, which were probably derived from the underlying Carboniferous. Cross-bedding dips west.

A cut on the State road east of Guthrie Center, in section 4, township 79, range 31 west, shows the following section:

	Feet
(4) Sandstone, coarse, yellow, streaked with brown limonite; beds 2 to 3 inches; small pebbles on bedding planes	1
(3) Gravel like that described above	7
(2) Shale, bluish gray mottled with brown spots	11

(1) Sandstone, coarse to medium, yellowish brown; beds 1 inch to 2 feet; some beds of conglomerate cemented by manganiferous limonite; iron concretions.. 8

A ravine along the southwest side of the State road south of Guthrie Center, in section 9, township 78, range 31 west, shows excellent sections of higher beds. A layer of bluish gray shale 20 to 25 feet thick overlies an equal thickness of fine, rather poorly sorted, light yellow, soft sandstone. The rock is finely laminated and the beds are heavy, some of them several feet in thickness. Cross-bedding is abundant and dips in nearly all directions except east. On the bedding planes are pebbles like those in the conglomerates.

In the east part of section 16 of the same township is a gravel pit in a disintegrated conglomerate. There are nodules of conglomerate cemented by limonite. The upper part of the deposit is of a rusty yellow color, but the lower portions are gray to white.

The base of the Cretaceous seems to rest on a surface of rather low relief at an elevation of about 1,050 feet. The deposits are so very similar to those of the Windrow formation that there is a decided probability of their equivalence.

The possibility of the equivalence of the Windrow formation to the Rockville conglomerate of McGee (15, 16, 7) has been considered and the type locality of the latter (southwest ¼, northwest ¼, section 24, township 88, range 3 west), near Dyersville, was visited by the senior author in 1919. No ledge or outcrop was found, but merely loose boulders of drift gravel cemented by limonite. The material is totally unlike that of the recognized Windrow formation in the poor rounding of the pebbles and the presence of igneous rocks and can hardly be correlated therewith.

MINNESOTA

The only deposits in Minnesota which can with any probability be referred to the Windrow formation are the quartz pebble conglomerates described by Winchell (31, 33) in Fillmore and Mower counties (southwest ¼, section 15, and southeast ¼, section 8, township 102, range 13 west; north ½, section 13, middle section 12, northeast ¼, section 11, and southeast ¼, section 3, township 103, range 14 west). The underlying rock is the Devonian limestone. The elevations of these localities vary from 1,300 to 1,350 feet. Limonite is present only at the first named, where it is known from well records. Winchell describes the conglomerate as "a beautiful coarse gravel, the greater part being white, often limpid quartz, the size of the pebbles varying from that of a pea to that of a hazel-nut." At other places the deposits are described as "white pebbly conglomerate which passes into a ferruginous grit."

In Goodhue County (11, 31) are exposures of clays and sands with associated conglomerates at elevations of 1,050 to 1,150 feet. Some of the sandstones contain fossil leaves which have been referred to the Cretaceous. The deposits are believed by Sardeson (21) to have been glacially transported from another locality. There is no good evidence connecting these deposits with the Windrow formation.

ILLINOIS

Salisbury and others (20, 21, 29, 34, 35) mention occurrences of gravel in Illinois and suggest their probable equivalence with the gravels of the Windrow formation. Some of them rest on the tops of ridges, and these may be of the same origin and age as the Windrow formation. Others appear to be merely preglacial stream terrace deposits. The available published information is not sufficient to enable the authors to decide which of the occurrences may be of the same age as the Windrow formation. The elevations of none of these localities greatly exceed 700 feet.

OTHER STATES

Salisbury (20, 21) mentions high-level gravels in Missouri, Kentucky, and Arkansas, which he thought might be correlated with the Devils Lake deposit. The junior author has seen a few occurrences of chert and quartz pebbles on the hilltops of Kenton County, Kentucky, and this material is very like that in the Windrow formation.

Fossils

No fossils have been discovered in the Windrow formation which are of the same age as the deposit, unless the conglomerates and associated deposits in Guthrie and Carroll counties, Iowa, in which leaves of Mesozoic aspect have been found and the Goodhue County, Minnesota, clays which contain Cretaceous leaves belong to the formation. Fossils of older formations are common in the chert pebbles.

In Wisconsin fossils have been collected at four localities. Their occurrence at Devils Lake has long been known. The writers have found them at Tunnel Number 3, Summit, and Windrow Bluff.

Salisbury (21) lists the following forms from Devils Lake as identified by E. C. Quereau:

Astrocerium venustum Hall, Niagaran.
Zaphrentis cf. *turbinata* Hall, Niagaran.
Callopora elegantula Hall, Niagaran.
Retopora sp., Niagaran.
Orthoceras junceum Hall, Galena-Trenton.

Specimens collected by W. C. Alden, from the same locality and identified by E. O. Ulrich (1) are:

Climacospongia near *radiata* Hinde, Niagaran.
Amplexus sp.
Favosites aff. *F. asper* D'Orbigney, Niagaran.

From quite a large collection made at Devils Lake in 1916 by Lawrence Martin, the junior author has identified those listed below:[4]

Hindia spheroidalis Duncan, Silurian.
Enterolasma cf. *caliculum* (Hall), Silurian.
Halysites catenularia Linn. (Hall), Silurian.
Favosites hisingeri Edwards and Haime, Silurian.
Streptelasma cf. *corniculum* Hall, Ordovician.
Cornulites sp.
Fenestella sp., upper Niagaran.
Helopora sp., Silurian.
**Atrypa reticularis* Linn., Silurian.
Hebertalla sp., Ordovician.
Pentamerus cf. *oblongus* (small) Sowerby, Silurian.
**Rhynchotrema capax* Conrad, Richmond.
Schuchertella cf. *subplana* (Hall), Silurian.
Pleurotomaria sp.
Crinoid segments.

Those marked thus * are well preserved and very little worn and can not have been derived very far from where they were collected.

The Summit and Tunnel Number 3 localities are listed together. Fossils are quite abundant at each place. From these two localities the following have been identified:

Cladopora sp., Silurian or Devonian.
Favosites favosus (or a closely related species) Goldfuss, Silurian.
Favosites cf. *niagarensis* Hall, Silurian.
Halysites catenularia Linn., Silurian.
Lyellia cf. *americana* Edwards and Haime, Silurian.
Strombodes mamillaris Owen, Silurian.
Cystodictya sp., Silurian or Devonian.
Eridotrypa sp., Silurian or Devonian.
Fistulipora sp., Silurian or Devonian.
Helopora sp., Silurian or Devonian.
Pseudohornera sp., Silurian or Devonian.
Pentamerus sp., Silurian.

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[4] For the identification of the bryozoa and sponges the writers are indebted to Dr. R. S. Bassler. His statements relating to the pebbles sent him are as follows: "With the specimens now being returned to you I have placed generic determinations and a guess as to age. It seems to me that practically every one of the pebbles comes from the Silurian of about Upper Niagara time, but it is possible that some of them are Devonian. At any rate, I have not seen an Ordovician species among them."

Howell lists a considerable number of fossils from the iron ore at Waukon which were derived from the rock immediately below (11). In chert pebbles collected by the senior author the following have been identified:

Favosites sp., Silurian or Devonian.
Atrypa reticularis Linn., Silurian.

The chert pebbles in the Cretaceous conglomerate contain forms similar to those of the recognized Windrow formation. Bain (4) lists the following as identified by Calvin. The senior author has collected fossils from the same horizon:

Cyathophyllum sp.
Bryozoa, Devonian?
Spirifer cf. *S. eudora* Hall, Niagaran.
Favosites favosa Goldfuss, Niagaran.
Favosites hisingeri Edwards and Haime.
Favosites cf. *F. hispidus* Rominger, Niagaran.
Streptelasma sp.
Streptelasma spongaxis Rominger, Niagaran.
Ptychophyllum expansum Owen, Niagaran.
Zaphrentis stokesi Edwards and Haime, Niagaran.

Origin of the Windrow Formation

PREVIOUS VIEWS

Strong considered the gravels near Seneca (25) to have been deposited by ocean currents and cemented by iron oxide coming from ferruginous springs or some other cause operating to precipitate iron from water. Irving (14) considered that the gravels and pot-holes at Devils Lake record a higher level of the preglacial Wisconsin River. Chamberlin and Salisbury ascribe the conglomerate at Seneca either to the marine Cretaceous or to the older drift (9). Salisbury first recognized the wide extent of the upland gravels and correlated them with the high-level gravels to the south, but did not make clear his views as to their origin (20, 21). Howell ascribed the deposits at Waukon, Iowa, to accumulation in a bog on a peneplain (12), a view earlier stated by Calvin for the same deposit (6). Trowbridge, Shipton, and Hughes considered that the gravels originated as stream deposits on a Tertiary peneplain (13, 22, 24, 26, 27, 28).

CRITERIA OF ORIGIN

Criteria relating to the origin of the Windrow formation may be divided into four groups, as follows: composition and assortment of ma-

terials, sedimentary structures, distribution of deposits, and nature of the underlying surface.

COMPOSITION AND ASSORTMENT OF THE MATERIALS

The materials of the Windrow formation fall into two general groups: (1) the pebbles and associated sands and clays, and (2) the iron oxides. The chert pebbles are shown by their fossils to have been derived from Paleozoic limestones, none of which was younger than the Devonian. Most of them came from the Niagara dolomite. They are generally highly polished, and well rounded specimens are extremely rare. At Devils Lake a few chert fossils were collected which show practically no wear. These facts prove that the transportation of the cherts has greatly varied, and, as so few of them are well rounded, it follows that they have not been subjected to much washing and are probably of stream rather than of beach origin. The quartz pebbles do not appear to have been derived from any of the Paleozoic formations now exposed in the upper Mississippi Valley, and it is quite probable that their mother rock is in the pre-Cambrian. All are well polished and rounded, but not one of lenticular shape has been found. It is concluded that they have been brought a great distance by streams and were not washed along a beach. If the surface on which the Windrow formation rests be projected northward, it will be seen that the nearest possible source for the quartz pebbles is the pre-Cambrian of northern Wisconsin, Michigan, or Canada. It is possible that the pebbles did not make their journey in one period; they may have been formed into a conglomerate which was later destroyed to make the Windrow formation. If so, no direct evidence of the existence of such a conglomerate has been discovered.

The assortment of the gravels and associated sands is very poor. Chert and quartz pebbles are intimately intermixed, and in a small hand specimen variations in size from a tenth of a millimeter to two or three centimeters is common. The sandstones show similar imperfect assortment. These characters, while they do not preclude marine deposition, strongly suggest river origin.

The iron oxides are present as concretionary masses which range up to several tons in weight and as a cement for the pebbles and the sands. They are characterized by a variable state of hydration and by the presence of a variable percentage of manganese, phosphorus, and clay. Included in the iron ores are boulders of the underlying rock, unworn silicified fossils, and lenses of conglomerate. The intimate association of the different kinds strongly suggests, if it does not prove, that their deposition took place simultaneously. The iron oxides are of the bog ore

type and the source of the iron was probably the residuum of the older rocks. Only locally has replacement of limestone by iron oxide been observed.

SEDIMENTARY STRUCTURES

These consist of bedding and lamination and ripple-marks. Such bedding as has been observed is poorly defined. Cross-lamination was observed in a few places. The iron-bearing portions show essentially nothing in the way of bedding, but this is possibly due to the development of concretionary structure subsequent to deposition, which would have brought about the elimination of bedding. A few current ripple-marks were observed at Tunnel Number 3. None of the structures suggest marine origin and all are in harmony with the view of stream deposition.

DISTRIBUTION OF THE DEPOSITS

In its existing occurrences the Windrow formation consists of isolated patches scattered over a wide area. (See map, figure 1.) It might be assumed that the known deposits of the Windrow formation are remnants of a one-time continuous sheet, but the irregular local occurrence of patches of gravel where conditions for preservation are apparently similar—their occurrence in a locality at a certain elevation, while only a short distance away no pebbles occur at that elevation—suggests that in their former distribution the gravels were never continuous. The theory of a once continuous sheet is a necessary consequence to the view that the gravels are marine conglomerates; but, if they are stream deposits, it is very improbable that the patches were ever continuous and the present distribution is readily explained.

It has been suggested that these gravels were deposited on a peneplain (13, 24, 26, 27, 28). To the writers this does not seem a necessary conclusion. The surface beneath the pebbles cuts across all formations from the Huronian to the Carboniferous, but that is what occurs in the valley of any stream; so that this fact alone does not prove the existence of a peneplain. The size of the pebbles, the distance some of them must have been transported, the pot-holes at Devils Lake, and the deep crevice filled with gravel at Seneca do not agree with the usual conception of the slow-flowing streams of a peneplain. These characteristics are more in harmony with valleys with a considerable extent of floodplain, with considerable gradient to the stream bed, an occasional fall or rapid, and divides of considerable height.

NATURE OF THE UNDERLYING SURFACE

The nature of the surface underlying the Windrow formation is known at only four localities. At Devils Lake it is a water-worn quartzite in

which are pot-holes a foot or more in diameter. The presence of these proves a rapids or falls which it is rather difficult to believe were made other than at the time the gravels were deposited. At Waukon, Iowa, test pits are stated to have found the ore to be separated from the underlying dolomite by a foot or two of residual clay. Unworn fossils and boulders from the underlying rock are present in the iron oxide. The stream at that place was not so swift as at Devils Lake, and bog ore could deposit against banks of dolomite. At Seneca the conglomerate penetrates 65 feet into a fissure in the bedrock. Whether it came into this fissure during or since its origin can only be conjectured; but, considering the generally impervious character of this material where iron oxide is present, it is more probable that the deposit was washed into a fissure at the time of deposition. At Mitchell, Iowa, the Windrow formation fills an erosion channel in fresh Devonian limestone. In Guthrie County, Iowa, the surface of the underlying Coal Measures beneath the Cretaceous is rarely seen, but appears to be one of comparatively small relief.

CONCLUSIONS AS TO ORIGIN

The surface on which the patches of the Windrow formation rest bevels across the Huronian and Paleozoic strata, descending from 1,440 feet at Devils Lake to about 1,300 feet along the Mississippi, about 1,100 feet in northern Iowa, and, if the conglomerate of southwestern Iowa is a part of the formation, it descends in that locality to about 1,050 feet. The quartz pebbles were probably derived from the north or northeast of their present distribution. It is suggested on subsequent pages that the gravels were deposited during the Cretaceous period. The Cretaceous sea lay to the south and west. The pebbles are believed to be of stream deposition in a region of considerable relief, and to have been deposited by streams flowing to the south and southwest. The absence of cherts containing Mississippian and Pennsylvanian fossils is in harmony with this conclusion, since such most certainly would have been among the pebbles, had the streams flowed in the opposite direction.

Age of the Windrow Formation

PREVIOUS OPINIONS

With slight reservations, Winchell and Upham ascribed the gravels and associated deposits of southeastern Minnesota to the Cretaceous (30, 31, 32, 33). Salisbury considered that "it is not beyond the possibility that some of the beds . . . are Cretaceous, while others are Tertiary"; but that "the balance of evidence seems to favor" reference to the latter (20). Howell concluded that "it [the plain on which the gravels occur] may be

assumed with considerable confidence to be of Pliocene age, since it bears gravels which belong to the Pliocene Lafayette formation" (12). Trowbridge appears to hold a similar view (13, 23, 24, 26, 27, 28). Chamberlin and Salisbury (10) discussed these gravels under the Pliocene, but suggested that they may be of older age.

CRITERIA RELATING TO CORRELATION

There are two problems involved, the correlation of the occurrences with each other and their correlation with deposits of known age. In the discussion which follows the two problems are not separated. Criteria which bear on the age of the gravels of the Windrow formation may be divided into six groups: (1) lithological similarity, (2) topographical position, (3) fossils, (4) age of underlying formations, (5) relation to overlying formations, and (6) history since the advent of glaciation.

LITHOLOGICAL SIMILARITY

The correlation of the different occurrences of the Windrow formation with one another is in large part based on their lithological similarity. Such differences as exist are quantitative, not qualitative. This fact, taken in connection with other evidence, leads the writers to the conclusion that the Windrow deposits as far west as Mitchell County, Iowa, are of the same age.[5] The gap of 120 miles from Floyd County to Guthrie County, Iowa, is more difficult to bridge. There seems little doubt that the Guthrie County beds are Cretaceous, and could a correlation of these basal Cretaceous gravels with those of the Windrow formation be definitely established, the age of the latter would be determined. The correlation of the Windrow formation with the high-level gravels of Illinois is even more difficult and hesitation is felt in attempting such. Whether or not the upland gravels of Buffalo County, Wisconsin, belong to the Windrow formation is an open question. They are much less like it than is the Cretaceous of southwestern Iowa, but, on the other hand, they are not like any known drift in that they lack igneous rocks. The larger stones are possibly all of local origin and none found is striated. It seems improbable that all the igneous rocks could have been destroyed by weathering, for they are present in what has generally been considered the oldest known drift, the Nebraskan. It is certain that these gravels antedate the valleys, and so are presumably of pre-Pleistocene age.

[5] In this connection it should be stated that the writers do not assume the gravels were necessarily deposited within a period of time represented by any marine formation. An entire period may have been involved and some portions of the gravels may well be somewhat older than others, but they are believed to have been deposited within a space of time throughout which there were maintained the same general conditions of deposition over the area of distribution.

TOPOGRAPHIC POSITION

One of the strongest lines of evidence tending to show the great age of the Windrow formation is its topographic position. Most of the known occurrences are on the summits of the highest land in the vicinity. At Devils Lake the gravels are over 500 feet above the surrounding country and close to 900 feet higher than the rock bottom of the preglacial gorge of the Wisconsin River. The Waukon deposit is about 900 feet higher than the rock bottom of the Mississippi Valley to the east, while the Windrow Bluff occurrence is over 800 feet above the rock bottoms of the adjacent valleys. East of the last-named point the strata on which the Windrow deposits rest have been entirely removed over thousands of square miles, leaving the great central plain of Wisconsin. These topographic features took a long time to make and they seem to have been in essentially their present form at the beginning of the Glacial period. The harmony of the elevations above sealevel is an additional argument that the different patches of gravel were deposited at essentially the same time.

It has already been suggested, in the consideration of the origin of the Windrow formation, that it was deposited by streams under conditions of considerable relief. Such being the case, it follows that at the time of the deposition of the gravels the present location of the deposits were the lowest parts of the surface instead of the highest, as they are today. The divides have migrated, so that what once was a valley bottom is now the top of a ridge. Such has, doubtless, been brought about in part by the resistance to erosion of the iron-oxide deposits, and an intervening period of peneplanation is not a necessary consequence in the sequence of events. The nature of the gravels suggests fairly wide valley bottoms with fairly high divides. Hills doubtless rose to considerable heights along the stream courses, and from their erosion the chert pebbles were derived. The crevice at Seneca, Wisconsin, if formed at this time, indicates sufficient relief to permit the formation of caves. If we imagine the country as it appeared when the deposits were laid down and realize that not only have the stream courses moved through the complete elimination of the former divides and have entrenched themselves 800 to 900 feet below the former levels of their valley bottoms, but that over thousands of square miles they have totally removed everything to this thickness, so as to form the great central plain of Wisconsin, then we obtain some conception of the age of the Windrow formation.

FOSSILS

No fossils have been collected in any of the deposits which are contemporaneous therewith. The cherts have yielded fossils which range in age

from the Ordovician to the Silurian and possibly the Devonian. This gives positive assurance that the gravels are of post-Silurian age.

AGE OF THE UNDERLYING FORMATIONS

The youngest rocks known to certainly underlie the Windrow formation are of Devonian age. If the Guthrie County, Iowa, conglomerates are part of this formation, then the Windrow formation is post-Carboniferous.

RELATION TO OVERLYING DEPOSITS

The materials known to overlie the Windrow formation are the glacial drift and the loess. This relation proves that the formation is older than these deposits.

HISTORY SINCE THE ADVENT OF GLACIATION

The earlier glaciers found the topography of the Driftless Area not greatly different from what it is today. They apparently entered the central plains area of Wisconsin in Wood and Jackson counties, thus showing that this plain is of pre-early-drift age, and that the Windrow formation long antedates the time of these glaciers. The erosion which has taken place since the retreat of the earliest ice in Wisconsin is a mere nothing compared to that which has occurred since the formation of the upland gravels and bog ores.

Unless the time necessary for erosion of such great valleys and lowland plains as have been formed since the deposition of the Windrow formation is much less than is generally thought necessary, the entire Tertiary period does not seem too long, in the opinion of the writers, to have brought about the existing stage of topography. It is true that in the western mountains huge canyons have been carved since Middle Tertiary time, but the conditions of climate and slope are there vastly different from those which could ever have existed in Wisconsin; so that the comparison is not fair.

Summary

The statements which follow summarize the general facts relating to the Windrow formation and writers' conclusions based thereon:

(1) The Windrow formation consists of gravels and conglomerates with quartz and chert pebbles and of associated bog iron ores which in part make up the cement of the conglomerates. Some sandstone and clay are also present.

(2) The formation rests unconformably on formations ranging from the Huronian to the Devonian and possibly the Carboniferous. It is overlain by loess and glacial drift.

(3) The surface of the underlying rocks is weathered and is locally stream-worn.

(4) The distribution of the Windrow formation is discontinuous and there is little to suggest that the present isolated patches were ever parts of a continuous sheet.

(5) The bedding is poorly defined, the assortment is extremely poor, the quartz pebbles are well rounded, and the chert pebbles are poorly rounded. All the characteristics of the formation show that it was deposited in streams of considerable velocity. The iron oxides were deposited contemporaneously in bogs along the stream courses.

(6) Judging from the size of the pebbles, the deposits were made under conditions of some relief. No evidence has been observed which necessitates connecting them with a period of peneplanation.

(7) Since the origin of the Windrow formation the region of their occurrence has experienced great erosion; divides have migrated and the streams entrenched themselves to a maximum depth of nearly 900 feet; hundreds of feet of strata have been stripped off from areas of thousands of square miles.

(8) The Windrow formation closely resembles the Cretaceous conglomerates of western Iowa. The stream courses in which it was deposited appear to have led to the Cretaceous sea to the west.

(9) The chert pebbles were derived from Ordovician, Silurian, and possibly Devonian strata, which must have once had a much wider distribution than at present. The quartz pebbles were probably derived from the veins of the pre-Cambrian.

(10) All lines of available evidence connect the Windrow formation with the Cretaceous period.[6]

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[6] Since the above paper was sent to press an article entitled "The erosional history of the driftless area," by Dr. A. C. Trowbridge, has appeared as number 3 of volume ix, University of Iowa Studies—Studies in Natural History. In this paper the gravels of the Windrow formation are discussed under the title of upland fluvial deposits (pages 78, 79, 111-113, and 121-123). Trowbridge concludes that they are the product of stream deposition on a peneplain. He places their age as probably late Tertiary (page 123). This conclusion is based mainly on the fact that he finds chalky particles in the Cretaceous gravels of Minnesota which are absent in the gravels of the Driftless Area, which latter "are strikingly similar to the Tertiary gravels of the Gulf region" (pages 122, 123). He also concludes that the surface on which the Windrow formation rests, when projected, fits better with the surface beneath the Tertiary than with that beneath the Cretaceous (page 122). This correlation makes the age of the valleys of the Driftless Area mainly post-Nebraskan—a conclusion which the author thinks is backed by the absence of ice erosion and stream diversions within the valleys of northeastern Iowa where Nebraskan drift is present on the divides (pages 124, 125).

There is, however, no direct evidence to show how much older the gravels are than the valleys. If the latter are in large part post-Nebraskan, it requires either a longer duration of the Pleistocene than is currently accepted or a greater rate of erosion in the early part of that period than in the later part, or both.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

OBSERVATIONS ON THE MODE OF LIFE OF PRIMITIVE CEPHALOPODS[1]

BY RUDOLF RUEDEMANN

(Read before the Paleontological Society December 29, 1920)

CONTENTS

Owing to the fact that we have today only the pearly nautilus, a still little known deep-sea form, for comparison, there still exists much doubt in regard to the mode of life of the Paleozoic Nautiloidea. To cite an example, the simple straight-shelled *Orthoceras* is considered by some good authorities to have been a bottom crawler, by others as having swum in a vertical position, and by still others as having buried himself in the mud in an upright position, or as having been fixed at the apex. There are few facts known that could shed light on the mode of life of these early cephalopods, and it is therefore thought worth while to record here some new biologic observations on these creatures.

INDICATIONS OF A CRAWLING MODE OF LIFE

a. FROM COLOR BANDS

The Trenton limestone of New York has afforded a number of specimens of *Orthoceras* (*Geisonoceras*) *tenuitextum* (Hall) that retain reddish brown color lines on a white background. These lines are found only on one side; they are thickest in the middle of the colored area and become separated by wider interspaces in the transitional zones and are

[1] Manuscript received by the Secretary of the Society March 3, 1921.

entirely absent on the opposite side. The color bands, which probably consisted of melanin pigments, enter the shell substance about one millimeter deep, and are so resistant to solution and weathering that they have given to many slightly etched shells a fluted appearance, which fact has led to the description of a different species, *Orthoceras strigatum* Hall. The color bands lie below the fine surface sculpture consisting of intersecting vertical and longitudinal lines.

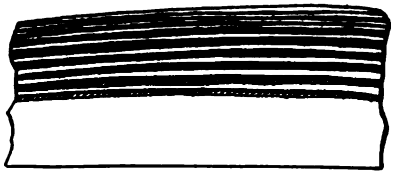

FIGURE 1.—*Geisonoceras tenuitextum* (Hall)

Lateral view of portion of conch with color bands. Natural size.

We see in the phenomenon of the coloring of the shells on one side only direct evidence that the species in question was given either to crawling on the bottom of the sea or to swimming in a horizontal position, either of which habits would have developed a differential coloring on the dorsal and ventral sides. It seems improbable that the long and straight cones could have been carried horizontally in swimming, especially since the creatures, like their descendants, would have swum backward, and thus exposed the delicate shells to frequent collisions and fracturing.

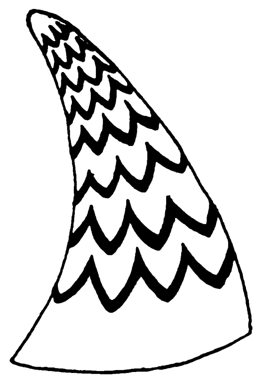

FIGURE 2.—*Cyrtoceras parvulum* Barrande, *with color bands*

Natural size.

There is other evidence available that supports the view that the conchs, buoyed up by gas in the air chambers, were lightly dragged over the soft mud by the sluggish animals. One of these is that the shells on closer inspection turn out to be no regular cones, but to be gently curved, so that the side with the color bands is slightly convex, while the other (ventral) side is straight or even a little concave.

Another observation that corroborates the explanation here given is that specimens of the same species found in the Utica shale are sometimes overgrown with a bryozoan (*Spatiopora lineata* Ulrich, var. *compacta* nov.), whose zoarium begins to grow near the apex and thence extends forward toward the aperture of the shell; also on one side of the shell only. If the bryozoan had attached itself after the death of the cephalopod, it would hardly have grown *pari passu* with the shell.

Specimens of *Orthoceras* (*Protokionoceras*) *trusitum* Clarke and Ruedemann from the Guelph limestone at Rochester have also been found to

possess color bands on one side. Silurian species of *Cyrtoceras* with short curved shells and other breviconic forms have been found by Barrande to have been embellished with transverse zigzag color bands that passed entirely around the conch. It is quite obvious that both color-markings and form of conch are in both groups of shells in perfect harmony with their mode of life—in *Orthoceras* with a crawling habit, in which the conch is dragged behind; in the breviconic species of *Cyrtoceras* with a crawling habit, in which the shell is carried obliquely or fairly upright and, as suggested by the position of the hyponomic sinus on the convex side, with the apex pointing forward.

The differentiation between dorsal and ventral color-marking is lost in the breviconic forms, both sides being equally exposed to light and sight.

b. FROM SECONDARY DEPOSITS

Certain of the straight-shelled forms possess secondary deposits in the air-chambers. It has been found that in some of these, notably *Actinoceras tenuifilum* (Hall) from the Black River (Watertown) limestone of New York and Canada, the secondary deposits which cover the inside of the outer wall and the upper side of the septa abut in thick rings against the nummuloidal segments of the siphuncle in such a fashion as to form a structure that increases the resistance of the shell against being crushed. Such a structure was of use only if the shell was dragged horizontally over the ground. Forms like *Gonioceras,* with planoconvex section of the shell and broad, low apertures, indicate already, by their form, their crawling habit.

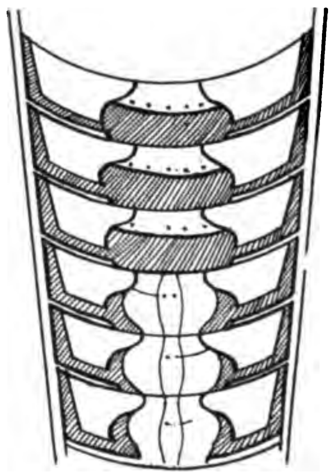

FIGURE 3.—*Actinoceras tenuifilum* (Hall)

Section through portion of conch, showing secondary organic deposits of carbonate of lime (shaded); lower part, section through siphuncle. Natural size.

Differentiation in Size of Sexes

Another group of observations points to early differentiation in the size of the sexes in some of the Paleozoic cephalopods. The Upper Utica shale at Holland Patent, in New York, contains, in close association in the same bed, three different forms of breviconic cephalopods, namely, a larger and a smaller form with contracted apertures and a smaller form

with wide-open apertures. According to the usual procedure, these would be distinguished as different species, the first two as belonging to *Oncoceras,* the third as a *Cyrtoceras.*

The fact that both the larger and smaller forms with contracted apertures exhibit more closely arranged septa just below the living chamber indicates that the contracted apertures actually indicate a gerontic condition, and that both forms, the larger and the smaller, had reached or passed maturity. Outside of this difference in size, the two forms agree absolutely in all other diagnostic characters, as relative rate of growth, depth of cameræ and septa; and likewise does the third form, with wide-

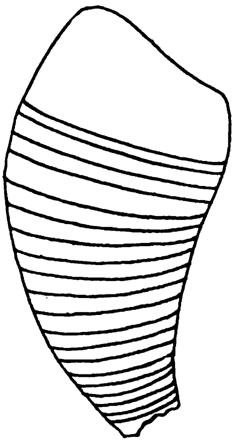

FIGURE 4.—*Oncoceras pupæforme* nov.

Mature female. Natural size.

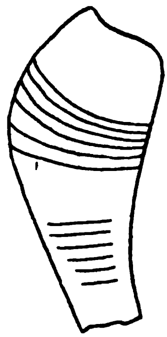

FIGURE 5.—*Oncoceras pupæforme* nov.

Mature male. Natural size.

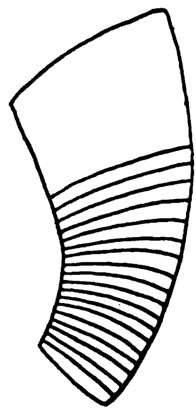

FIGURE 6.—*Oncoceras pupæforme* nov.

Immature female. Natural size.

open aperture, fail to show any other differences suggestive of specific distinction. This third form is also of smaller size and ranges between the smaller and larger forms.

We consider these three forms as belonging to a single species of *Oncoceras* (to be described in another place), the larger and smaller forms, with contracted apertures, representing the mature females and males respectively, and the intermediate form, with uncontracted aperture, the immature females.

The conclusion that the larger shells contained the females of the species and the smaller ones the males is based on the observation in recent cephalopods that, as a rule, the males are more slender or smaller than the females. In *Argonouta,* where the maximum of sexual dimorphism is found, the females are as much as 15 times as long as the males.

While there already exist observations made by European scholars on sexual dimorphism among the Mesozoic ammonites, we are not aware of such regarding the Paleozoic nautiloids. Barrande noted the wide differences in the relative lengths of the living chamber in the same species of *Orthoceras,* but saw in them but individual variations in size. We consider it very probable that they also denote a difference in the size of the sexes.

Synchronic relation of Septa to Growth-lines

A further observation on an Ordovician species of cephalopods relates to the origin of the septa.

A species of *Orthoceras,* namely, *O.* (*Geisonoceras*) cf. *transversum* Miller, has been found in the lower Lorraine shale preserving (on specimens that are compressed into a single plane and whose substance is totally dissolved) in the same plane both the septal sutures and the surface sculpture. It is seen in these specimens that the transverse growth-lines of the sculpture are crowded at regular intervals, and that these intervals exactly correspond to the depth of the cameræ or to the distances between the septa as indicated by the sutures. Assuming that the crowded growth-lines denote periods of rest in the growth of the animal, it follows that the septa likewise indicate regularly returning periods of rest following times of rapid growth. These periods of rest are believed to correspond primarily to the periods of reproduction in the mature specimens. The periods of rest and sexual production, in which the septum was formed, alternate regularly with periods of rapid growth and lengthening of the shell. The formation of the septa, which originated with the periodic interruptions in or a slackening of the rate of growth in the mature individuals, has by tachygenesis been carried back into the earlier growth-stages for the purpose of shutting off the unused portions of the conch and at the same time to strengthen it and provide air-chambers to buoy up the shells.

Figure 7.—*Geisonoceras* cf. *transversum* (Miller)

View of portion of compressed conch, showing growth-lines and sutures (dotted). × 2.

A similar periodicity in the growth of the shell is shown in the succession of flaring apertures of the Devonian *Rhyticeras cyclops* (Hall) and

similar types. In later forms the growth of the apertural margin seems to have become fairly uniform.

INTERIOR ORIGIN OF ANNULATION

I should like to add here an observation giving a suggestion as to the origin of the peculiar annulation observed in the Cycloceratidæ. An early annulated form of the Beekmantown of New York originally described as *Orthoceras cornu-oryx* (now *Orygoceras*) Whitfield possesses the annuli only as grooves on the inside of a rather thick shell that is smooth on the outside, so that the casts only appear annulated. These

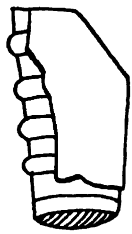

FIGURE 8.—*Fragment of Orygoceras cornu-oryx* (Whitfield)

Showing smooth exterior surface of shell and casts of interior annulation. Natural size.

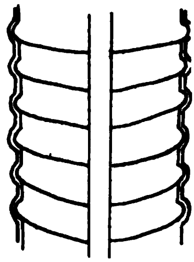

FIGURE 9.—*Protocycloceras whitfieldi* (Ruedemann)

Section of portion of conch, showing relation of annuli to septa. Natural size.

grooves suggest that the annulation may have originated on the inside of the shells by absorption from the necessity of gaining more room to place the probably voluminous sexual products. The observation that the annuli in the earlier forms, as notably the Fort Cassin species *Protocycloceras lamarki* and *P. whitfieldi*, exactly correspond in position and number to the septa seems to corroborate this inference of the original function of the annulation in these cephalopods. Later the annulation, which could hardly have been of advantage in the movement of forms that dragged their shells over the ground, appears to have persisted in the Cycloceratidæ, because of its lending greater strength to the shells.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

STATUS OF OUR KNOWLEDGE OF MESOZOIC PATHOLOGY [1]

BY ROY L. MOODIE

(Presented before the Paleontological Society December 29, 1920)

CONTENTS

Introduction

The subject of paleopathology is replete with pitfalls. When one recalls that the field covers all evidences of disease or injury from the Proterozoic to the civilization of the continents by the white races, the reasons for the pitfalls will be evident. I have, however, been emboldened by the example of others to widen my range of thought and have embarked on this difficult mission.

Definition of Paleopathology

The difficulties arise on every hand. First: Paleopathology is "dry-bone pathology," a subject held in some contempt by medical men, and in consequence the literature on the subject is widely scattered. One thus needs to build up a knowledge of modern human and animal pathology relating to the skeleton. Second: The determination of a disease and its pathology in modern medicine is by microscopic as well as by gross examination. Hence a knowledge of the histological nature of fossil bone was necessary. Such a review has been made and its results will be recorded. Third: One must venture out of his chosen realm of thought, and is likely to regard a geode as a tumor; a post-fossilization fracture

[1] Manuscript received by the Secretary of the Society March 3, 1921.

as evidence of caries; a normal muscular eminence as a callus following fracture. However, with care and the advice of kind friends, experts in their fields, the subject may be pursued with some profit.

The subject had its inception in a difficult way. While it was being studied and defined among Paleozoic animals in America, Ruffer, thousands of miles away, was studying and defining it among the ancient Egyptian mummies, the workers being equally unaware of the others. My work has been to fill in between the ancient evidence of disease in the Paleozoic and the evidences of pathology among ancient men. Hence a knowledge of "the status of disease during the Mesozoic" is essential to a proper filling out of the subject.

Mesozoic Pathology

We need not discuss at this time the origin of disease. It may have been present in the Proterozoic or it may have arisen later. I am inclined to think that our conception of the time of origin of disease will be modified by our definition of the term disease. It is a pity that the Permian is not a portion of the Mesozoic, for Permian pathology is more closely related to the Mesozoic than to the Paleozoic. However, to be orthodox, we shall begin our discussion with the Triassic. The following brief tabulation of Mesozoic pathology will aid in appreciating the degree of progress disease had made at this time.

I. Arthritides:

1. Spondylitis deformans (Diplodocus, Camarasaurus, Tyrannosaurus).
2. Multiple arthritis (Rheumatoid in Mosasaur).
3. Arthritis deformans (with osteoma and periostitis).

II. Tumors:

4. Osteoma (Mosasaur).
5. Hæmangioma (Apatosaurus).

III. Necroses:

6. Necrosis with hyperplasia $\left\{\begin{array}{l}\text{Jurassic crocodile,}\\ \text{Triceratops skull,}\\ \text{Camptosaurus,}\\ \text{Mosasaur radius.}\end{array}\right.$
7. Caries in Mosasaur.

IV. Hyperostoses:

8. Alveolar osteitis (Mosasaur of Belgium-Dollo).
9. Exostoses (scapula of Triceratops).
10. Gigantism (hyperostosis in Nothosaur).
11. Osteoperiostitis (humerus of Mosasaur).

V. Fractures:

12. Skull in Mystriosuchus (Triassic).
13. Oblique fracture in humerus of Hypacrosaurus and subperiosteal abscess.
14. Simple fracture in rib of Dinosaur.
15. Fracture (?) of tail, accompanied by osteomyelitis.

Presence of Bacteria

This array of fifteen pathological results is indeed a startling one. I do not say that this is *all* the pathology of the Mesozoic, but it is all I have seen or heard described, and serves merely as a basis for future knowledge. This array of diseased members argues for a long preceding history of pathology of which we are largely ignorant. The necroses and arthritides argue for the presence of Mesozoic pathogenic bacteria of various types which are otherwise unknown, although bacteria have recently been seen by me in an osteomyelitis from the American Permian.

Nature of Evidence

It will be more satisfactory to discuss briefly the evidence on which the above classification is made:

I. Arthritides: This is a group term used to define all pathological results found in or around the joint surfaces of the limbs, vertebræ, and skull. The lesions are the result of a great variety of diseases.

1. Spondylitis deformans: This is a type of pathology found around the articular surface of the vertebræ. It is the result of inflammation in the vertebral ligaments, caused either by infection or injury. It accompanies Pott's disease (vertebral tuberculosis) and may cause a complete rigidity of the spine. Coossified vertebræ are often indications of this form of pathology. The united caudals of *Diplodocus* described by Hatcher and Osborn are clearly examples of this type. Other coossified vertebræ in the dinosaurs are due to different causes. Thus the coossified caudals of Brontosaurus mounted in the Carnegie Museum is not Spondylitis deformans, but osteomyelitis. Spondylitis deformans has a curiously satisfactory geological history, being known in the Comanchean, Cretaceous, Eocene, Miocene, abundantly in the Pleistocene, and very common in the Recent epoch.

2. Multiple arthritis (Rheumatoid): This form of pathology, involving the great toe of a large Kansas Mosasaur, is the only fossil example known to me. This is a sort of Mosasaurian gout or rheumatism which must have caused the old fellow some inconvenience.

3. Arthritis deformans: Only two examples of this form of pathology are known to me, both accompanying other pathological lesions. The articular surfaces are only slightly deformed.

II. Tumors: These pathological growths, neoplasms, are not due to a definite infection and arise from preexisting tissues. Only two examples of tumors are known during the Mesozoic.

4. Osteoma: Seen on the dorsal vertebræ of a Kansas Cretaceous Mosasaur. Not to be confused with a hypapophysis, but is a true outgrowth of the vertebra.

5. Hæmangioma: This has been previously described and appears to be a true tumor. It occurs between two caudal vertebræ of a Comanchean Dinosaur.

III. Necroses: These are the definite result of bacterial or other infection. The various types can not be distinguished in a fossil condition. There are numerous examples known.

6. Necrosis with hyperplasia is present in the ilium of Camptosaurus in the U. S. National Museum and in a Mosasaur radius belonging to the University of Kansas.

7. Caries is not common among fossil vertebrates, although Dollo gives an example of it in the mosasaurs, and Leidy and Hermann have described it in the American mastodon. I have never seen an example of fossil dental caries.

IV. Hyperostoses: These are thickenings of bone, taking the form of outgrowths not classified in the preceding groups.

8. Alveolar osteitis, the result of pyorrhea, I have never seen in Mesozoic fossils, although Dollo has described it in a Cretaceous Mosasaur.

9. Exostoses are fairly common and assume a variety of forms.

10. The pathology of Gigantism, or extreme osseous hyperplasia, is suggested by Volz and Abel as an explanation of certain hypertrophied Nothosaur and fish bones.

11. Osteoperiostitis: This is a diagnosis assigned as the cause of the pathological excrescences seen in a Cretaceous Mosasaur from Kansas.

V. Fractures are of a variety of types, depending on the situation and the degree of pathology involved.

12. Skull fracture in the Triassic Mystriosuchus reported by von Huene. Occurs immediately anterior to the nares.

13. Oblique fracture with subperiosteal abscess seen in the humerus of Hypacrosaurus in the American Museum. A common form of pathology today. The bridge of bone present in the fossil humerus is due to an elevation of the periosteum by an enormous abscess capable of holding several liters of fluid.

14. Simple fracture, commonest type of fracture among fossil animals. An example in the mounted skeleton of Apatosaurus in Field Museum.

15. Fracture in tail of Brontosaurus with osteomyelitis.

Pathology of Reptiles

It will be apparent, especially to those interested in other lines of paleontological research, that the above discussion relates entirely to the fossil reptiles; and, indeed, I know no other Mesozoic pathology. The Mesozoic fishes, amphibians, birds, mammals, and hosts of invertebrates have not been drawn on at all, for the reason that I know very little of pathology in these fossils. The title of this paper should then read: "The status of disease during the Mesozoic as evidenced by the fossil reptiles." It is rather strange that nothing of pathology is known among the hosts of Cretaceous fishes. Various types of tumors are said to be common among recent fishes, but I know of no examples in the fossil condition in any age. This will show us clearly how meager indeed is our present knowledge of Mesozoic pathology and what great vistas of research are open to us for future exploration.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

EVOLUTION, PHYLOGENY, AND CLASSIFICATION OF THE MASTODONTOIDEA [1]

BY HENRY FAIRFIELD OSBORN

(Presented before the Paleontological Society December 30, 1920)

CONTENTS

INTRODUCTION

In previous papers reasons have been given for dividing the Proboscidea into four main superfamilies, as follows:

I. *Mœritherioidea*, typified by *Mœritherium*, Oligocene, North Africa.
II. *Dinotherioidea*, typified by *Dinotherium*, Miocene and Pliocene, Eurasia.
III. *Mastodontoidea*, typified by the bunomastodonts and the mastodonts, Africa, Eurasia, North and South America.
IV. *Elephantoidea*, typified by the stegodonts, loxodonts, elephants, and mammoths, Africa, Eurasia, North America.

[1] Manuscript received by the Secretary of the Society May 10, 1921.
This is the fourth paper of the series. The first paper, entitled "A long-jawed mastodon skeleton from South Dakota and phylogeny of the Proboscidea," appeared in the Bull. Geol. Soc. Am., vol. 29, No. 1, March, 1918, pp. 133-137. The second paper, entitled "Evolution, phylogeny, and classification of the Proboscidea," appeared in Amer. Mus. Novitates, No. 1, January 31, 1921 (1921. 514). The third paper appeared in Amer. Mus. Novitates, No. 10, June 15, 1921, under the title "First appearance of the true mastodon in America."

As clearly pointed out in the second paper on this subject (Osborn, 1921. 514, pages 2-5), these four superfamilies are clearly distinguished from each other by profound differences in the adaptations of the cutting teeth, namely, the first and second pairs of superior and inferior incisors characteristic of all Proboscidea. The author is not prepared at present to add to what has been said in previous papers regarding the mœritheres and dinotheres.

Species

Continued observation of the *types* on which the species in all parts of the world have been founded and of the *genotypes* from which the genera received their designations is gradually bringing order out of chaos. The synonymy in the 47 generic names is most difficult of solution. There is far less synonymy among the species; in fact, the specific and subspecific stages are far more numerous than has hitherto been supposed. It is not proposed at present, however, to multiply the species; rather to attempt to arrange the 170 or more species hitherto described in their natural lines of phyletic descent.

Phyla

There are still wide differences of opinion about the reality of the polyphyletic division of the Proboscidea. Such division is still considered a matter of theory, whereas it will be shown to rest on actual demonstration of a very profound divergence of many lines, due to the principles of adaptive radiation, local and continental.

In 1918 I divided the Proboscidea into *ten* phyla. In 1921 I divide them into *twelve* phyla. The application of generic names to these phyla presents a very difficult problem in nomenclature, on which I am securing the cooperation and advice of all the experts on this subject, especially of such leading authorities as Allen, Palmer, Matthew, Andrews, and Schlesinger. The difficulty arises from the fact, pointed out in my first paper, that the generic names were based on species which belonged within two, three, and sometimes four distinct phyla. For example, the generic name *Tetralophodon* Warren, 1852, was based on the species *M. latidens*, *M. arvernensis*, *M. sivalensis*, animals which certainly belong to two distinct phyla—stegodontines and brevirostrines. The same term, *Tetralophodon*, was applied by Falconer in 1857 to animals belonging to four distinct phyla, namely, *M. longirostris* (a longirostrine), *M. latidens* (a stegodontine), *M. andium* (an American brevirostrine), *M. arvernensis* and *M. sivalensis* (two Eurasiatic brevirostrines). The name *Tetralophodon* Falconer would apply admirably to *M. longirostris,* but unfortunately it

is preoccupied by Warren for *M. latidens, M. arvernensis,* etcetera, and therefore can not be used.

Parallelism

Again it is said that there are transitions between certain of these phyla; for example, between the longirostrines and the brevirostrines in the Pliocene of Europe. Such transitions may be observed in single structures, because the law of *parallel evolution* is constantly at work; for example, in the family Bunomastodontidæ there are at least four clearly distinct phyla, which we may at present separate as the longirostrines, the rhynchorostrines, the South American brevirostrines (*M. andium, M. humboldtii*), and the American *Trilophodon serridens* phylum (unnamed at present). All these animals are united by the common possession of the *bunomastodont* type of molars, composed of compressed inner and outer lobes, to which Cuvier applied the original term "mastodon," between which sprang up also single bunoid intermediate cones forming trefoils (*Phiomia, Trilophodon*), then gradually both internal and external trefoils, such as are found in the long-jawed *M. campester* and *M. longirostris* and independently arise in the short-jawed *M. humboldtii.* Thus the internal and external pairs of trefoils develop by parallelism in four separate lines of descent in the phyla belonging in the new family of Bunomastodontidæ (Osborn, 1921. 514), the phyla being united by this common *family* character as well as by the presence of a broad enamel band on the superior incisor teeth. They are still more clearly separated from each other by the elongation or by the abbreviation of the jaw or by the formation of a downturned or beaked jaw.

It is by this interpretation of the facts of descent, and by the exclusion of parallelism, and not by theory that we reach the polyphyletic subdivision of the Mastodontoidea, as follows:

Superfamily, Mastodontoidea

Family, Mastodontidæ	Family, Bunomastodontidæ
Grinding teeth lophodont, no intermediate cones or trefoils; all grinders with simple transverse crests; intermediate grinders evolving from two to three crests.	Grinders bunomastodont, with single developing into double trefoils; intermediate grinders. evolving from three into four crests.
Lower jaw gradually reduced in length.	Upper tusks with broad, persistent enamel band on outer concave surface, abrading the lower tusks.
Inferior canines, rounded tusks, not functional.	Lower tusks horizontal, oval or downturned, with or without enamel band.

Superior canines, rounded upcurved tusks, with enamel band on convex outer surface, gradually disappearing.

Subfamily, *Mastodontinæ* (monophyletic)

Genus, *Palæomastodon*, Oligocene.
Genus, *Mastodon*, Miocene to Pleistocene.

Subfamilies

(1) Longirostrinæ, (2) Rhynchorostrinæ, (3) Serridentinæ, subfamily nov., (4) Notorostrinæ, subfamily nov., (5) Brevirostrinæ.

Family, Bunomastodontidæ

The Longirostrinæ (1) and the Rhynchorostrinæ (2), also the Brevirostrinæ (5), have been clearly defined in previous papers.

(3) The *Serridentinæ* apparently spring from *M. turicense* Schinz, 1824, of the Middle Miocene of France and Switzerland—a rare animal, probably because a forest dweller. The grinders are readily distinguished by a prominent spur which projects from the inner apex of the crests in the lower teeth and from the outer apex of the crests in the upper teeth. It is recognized again in the Miocene Siwaliks of India. It appears again in the Lower Pliocene (*Trilophodon serridens* Cope) of the Clarendon beds of Texas; also in the *T. serridens cimarronis* of Texas, represented in the American Museum collection by a hitherto undescribed complete skull, which proves that this phylum belongs near the Bunomastodontinæ, although the grinding teeth lack the trefoils characteristic of that phylum. These animals have usually been placed with *M. tapiroïdes* of the lophodont or mastodontine phyla of France. They certainly possess cutting teeth of bunomastodont type and are probably remote from the true mastodontines.

(4) The *Notorostrinæ* include all the Central and South American brevirostrines, which are also abundant in the southwestern United States—for example, Texas (Blanco formation), Mexico, the Andean, and the Pampean regions. They were distinguished in my second paper as "The brevirostrines of South America," embracing the classic species *M. andium* Cuv., *M. humboldtii* Cuv.; also *M. tropicus* Cope (Valley of Mexico), *M. successor* Cope (Blanco of Texas). They possibly sprang from or are related to *Eubelodon morrilli* Barbour, 1913, from the Lower Pliocene, Nebraska. The fact that these animals are not only profoundly separated from the *other* bunomastodonts by the progressive abbreviation of the jaw, but that they are the only members of the great order Proboscidea which, so far as known at the present time, entered the South American continent, will probably convince reluctant paleontologists that

they constitute a distinct subfamily, which may be named the Notorostrinæ,[3] or short-jawed mastodons of the South American continent. There is a very great variety of form among the ten species which have been described, including, in addition to those mentioned above, *M. bolivianus* Philippi, *M. chilensis* Philippi, *M. platensis* Ameg., *M. rectus* Ameg., *M. argentinus* Ameg., and *M. superbus* Ameg. The two beautiful skulls in the Stockholm Museum, referred to *M. andium* by Nordenskjold, display a spiral twist of the tusks—a feature quite unique among Proboscideans.

Family, Mastodontidæ

As pointed out by Matsumoto, the lophodont *Palæomastodon* of North Africa is readily distinguished by the *absence* of intermediate cones and trefoils, which block the valleys in the contemporary genus *Phiomia;* its grinding teeth are purely crested or lophodont. It is also distinguished by its *bilophodont* superior intermediate molars, whereas those of *Phiomia* are fully *trilophodont.* The lower intermediate molars of *Palæomastodon* have only two complete crests and one small lobe representing a third crest instead of the complete third crest of *Phiomia.* Thus they have not attained the trilophodont stage characteristic of the genus *Mastodon,* but may lead into that stage. Although the skull is not fully known, it is relatively broader and shorter than that of *Phiomia.* The relative rarity of this animal in both the American Museum and British Museum collections is also in keeping with the theory that it was a forest dweller and that its remains, like those of all the Mastodontinæ, escaped fossilization until the true mastodons appear in enormous abundance in the Pleistocene forest formations of eastern North America.

It now appears probable that the Mastodontidæ sprang from the genus *Palæomastodon* of the Oligocene Fayûm deposits of North Africa, while the Bunomastodontidæ sprang from the genus *Phiomia* of the same deposits. From materials in the American Museum hitherto undescribed, Matsumoto has positively separated these two genera, the species of which have been more or less confused ever since the original descriptions of Andrews of *Palæomastodon* in 1901 and of *Phiomia* in 1902. *Phiomia* is certainly ancestral to the Bunomastodontidæ only, in fact, barely separable generically from *Trilophodon angustidens*, the typical longirostrine.

The name *Palæomastodon,* which has figured in all the literature from the date of its establishment to the present author's preceding paper (1921. 514), therefore applies only to the lophodont type of *P. beadnelli,*

[3] From the Latin of Virgil, "notus," a southwest wind; Greek, "Notogæa," the South American region.

on which it was founded, and can not be applied to the bunomastodont genotype of *Phiomia,* which was founded a year later by the same author. There is no question as to the absolute phyletic distinction between these two animals, but until the cutting teeth of *Palæomastodon beadnelli* are known we can not be sure that this animal is directly ancestral to the Mastodontidæ, as would appear.

Schlesinger has added several very important examples of true mastodons from the Lower and Middle Pliocene of Hungary, to which he gives the name *M. tapiroides americanus.*[4] The first appearance of the true *mastodon* in North America is in the Snake Creek formation, Lower Pliocene of western Nebraska, where a few teeth have been found by the American Museum and Princeton parties, one of which has been selected by Osborn as the type of *Mastodon matthewi.*[5] Its next occurrence is in the Thousand Creek formation of Nevada, Middle Pliocene, represented by two posterior grinding teeth in the collections of the Colorado Museum of Natural History, Denver, and of the University of California, which Osborn has made the type of the species *Mastodon merriami,*[5] in honor of President Merriam, of the Carnegie Institution.

These teeth, as well as those of the Lower Pliocene of Hungary, are readily distinguished from those of *M. americanus* by their more brachyodont character; the crests are low and spreading instead of being tall and narrow.

Summary

Research on this group is still in active progress, and from week to week the conclusions both as to phylogeny and as to classification are modified by the discovery of fresh or hitherto undescribed material and by the more careful analysis of the fundamental characters of the different phyla.

[4] Characters examined from an important unpublished memoir by Professor Schlesinger, original photographs of which were kindly forwarded to the present author.

[5] Amer. Mus. Novitates, No. 10, June 15, 1921. Immediately after the publication of this paper the author learned that the type of *Mastodon merriami* occurred in beds of Middle Miocene age, which makes it geologically older than *Mastodon matthewi.*

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CRITERIA FOR THE DETERMINATION OF THE CLIMATIC ENVIRONMENT OF EXTINCT ANIMALS[1]

BY E. C. CASE

(Presented before the Paleontological Society December 29, 1920)

CONTENTS

It is unnecessary for the speaker to apologize for the incompleteness of this summary paper, for within the limits of time at his disposal no adequate treatment can be attempted.[2] Simply an attempt has been made to set down in coherent form the main points which should be in the mind of every one who is attempting to determine the climatic environment of a fossil form or a group of fossil forms found in any definite bed.

The criteria suggested in this paper for the determination of the climatic environment are not such as might rationally be figured out in an office chair, but are such as have been used by the author in the field and are proven to be practical. Much that should be revealed, from all considerations of theory, is commonly hidden, for one reason or another, as every field-worker knows, but certain things can always, or generally, be observed and checked in the field and the laboratory.

Categories of Criteria

The criteria for the determination of the climatic environment can easily be placed in two categories, the organic and the inorganic. In the

[1] Manuscript received by the Secretary of the Society March 3, 1921.

This paper is one of a series composing a "Symposium on criteria and methods employed in paleontological research."

[2] The subject of the interpretation of sedimentary beds has been discussed at some length by the author in Publication Number 283 of the Carnegie Institution of Washington, where an attempt has been made to indicate how not only the climate but other environmental factors of past life can be made out.

first group belong all the suggestions which come from the animals themselves, with all the hints that come from their various adaptations and specializations. To this is added the important evidence of the association of various plants and animals in the same bed and in the same locality. In the second group belong the sediments of the inclosing beds, with the facts of their physical condition and mode of deposition, the facts of their original or altered composition, the nature of the cementing material, and the possible changes subsequent to deposition.

The first point in any determination is the recognition of the fact that most vertebrate fossils lie buried in sediments which do not represent directly the normal habitat of the animals. The sea-bottom was not the habitat of the free swimming forms, nor were the muds and sands of a swamp, a lake, or a river bottom the home of terrestrial animals. Only for such forms as normally lived in the actual area of deposition, as bottom-dwelling or palustral forms, can subaquatic sediments be interpreted as reflecting directly the climatic conditions during life. In almost every case the inclosing sediments have been transported from a terrestrial or semi-terrestrial position and laid down again after more or less profound changes due to erosion and transportation.

Inorganic Criteria: Character of Sediments

Primarily, then, the worker must determine whether the remains lie in sediments which directly reflect the environment or whether they are sediments which have been derived and transported from the area of the environment, and they can only be correctly interpreted after the changes inherent in such derivation and transportation have been reckoned with.

The changes which occur in derived sediments belong in the category of inorganic criteria. It is, perhaps, not usually expected that the student of animal morphology will be familiar with the tenets of physiography, or that he should be conversant with the principles of metamorphism, but the paleontologist of today is rarely so limited in his outlook that he is content with the mere description of new forms or with bare anatomical comparisons. Rather he is a paleogeographer, who acts on the principle that geography is the study of the response of the organism to its environment, whether he subscribes to that definition or not. He is much more interested in the factors which influenced the evolution of an animal or a group than he is in the direct evidence of evolution. For one, the author has found it wise to keep Van Hise's Treatise on Metamorphism and Clark's Data of Geochemistry within short reach when he is engaged on a problem of vertebrate paleontology, and he has found it equally wise to have some good treatise on physiography close to his hand.

It is obvious that the first suggestion of habits and environment must come from the morphology of the animals themselves, but it is equally obvious that any natural collection of vertebrate fossils must be due to unnatural conditions or processes of accumulation. If we are dealing with animals of terrestrial habit, the concentration of their remains in bone beds or in such quantities within any restricted area that they may be profitably exploited by the collector will be due to one of two conditions in almost every case: either they have been gathered together by currents of water after death, or they have been overcome by some catastrophe in the spot where the remains occur. In either case the interpretation of the climatic environment is sufficiently difficult, but it is certainly more difficult in the usual case, where the remains have been concentrated by currents of water after death, for here the sediments are not in their original position and their history must be read before the animal's habitat can be made out. The observer must have in mind, first, the physical and chemical changes due to erosion and transportation, and, second, the changes which have taken place since the time of deposition. These are problems for the geochemist and the geophysicist, but the paleontologist must for the time assume these tasks or leave the problem unsolved.

Unaltered Sediments

Consider first the possibilities of interpreting the sediments on the assumption that they have not been altered since their deposition. It must first be determined whether they are lacustrine, palustrine, fluviatile, littoral, or what-not. The determination of the character of the receiving basins of any area carries in itself far-reaching implications in regard to the climate. Next the observer turns to the physical condition of the sediments. The sizes and conditions of the grains and pebbles will tell of the volume and velocity of the transporting bodies of water which have borne the material from the land or in whose course it has been laid down. A little careful study will generally reveal whether the floods have been regularly recurrent or whether they have been sporadic. Wind-blown sand is not uncommon in many subaqueous deposits and its nature may be determined by microscopic examination. All these things reveal the climate.

Now the chemical and mineralogical character of the sediments. Even in the most altered sediments some portion will generally remain sufficiently unchanged to reveal the character of the dominant rocks of the land from which they were derived. If the land was dominantly hard rock, the history of the eroded and transported sediments will be very

different from that of sediments derived from a land of softer rocks. Obviously coarse, angular, or semiangular grains or pebbles, loosely piled and with the original minerals little changed, tell of rapid erosion and transportation by active streams, and if such beds are recurrent at fairly regular intervals the suggestion is of a humid climate with regular alternations of wet and dry seasons. If similar beds occur sporadically, the suggestion is one which will occur to every observer who has worked in an arid or semiarid region, where infrequent but violent storms occur between long intervals of drouth.

If the material derived from a land of hard rocks is thoroughly decomposed, it tells of a land where the eroded material lay long as a part of the residual soil in a climate of at least sufficient humidity to permit active chemical action by CO_2 derived in large part from decaying vegetation.

If the sediments were deposited on the littoral of a lake, on a great delta, on a river floodplain, or in the bed of an overloaded stream, their chemical composition and the nature of the cement gives a good idea of the prevailing height of the water-table, and this in turn reveals the general condition of humidity at the time. With a high water-table, the deposited minerals and the cement will be largely sulphides, hydrates, and the lower oxides; with a low water-table, there is possible a circulation of air and oxygen-bearing waters, and the minerals will be sulphates, carbonates, higher oxides, and even water-soluble salts in large quantity. The condition is revealed in part in the coloration and the texture of the beds as well as in the minerals themselves. The minerals of the latter series are less bulky and less firm in mass than the former and permit the presence of cracks and cavities.

Altered Sediments

If we assume the more difficult alternative, that the sediments have been altered during the long time since their deposition, we must reckon with the profound changes due to the infiltration of migrating waters or the drainage of the beds and the consequent changes due to oxygenation. Such changes are not usually so profound as to obliterate all traces of the original condition, and so the process may be detected. The migration of waters into sediments laid down under arid conditions tells their story in the presence of casts of crystals of water-soluble salts or pseudomorphs after such crystals, in the increase of bulk by hydration and the consequent disturbance of the beds, and in the deposition of minerals in the original cracks and cavities. Drainage and desiccation of the beds, originally water soaked, leaves its own peculiar record.

The climatic factor of temperature is far less readily determined than that of humidity. Glacial conditions in their extreme development are determinable in the character of the deposits. The oncoming of a glacial climate is only to be argued from more obscure bits of evidence of a general character, as progressive elevation and perhaps increasing aridity due to the elevation. But here the location of the area with regard to barriers to the prevailing wind must be considered. On the whole, this phase of the evidence is not satisfactory.

More positive evidence of the temperature may be gained from the plant remains, if it is certain that they are in the region of their true habitat. We have some definite information of the relation of the habit of growth, shape of leaves, etcetera, to temperature which is usable.

Dare we hope that some time a sufficiently definite determination of the relation of climate to periods of volcanic activity will be made, so that we may show some relation between the animals buried in showers of volcanic ash or inclosed in sediments of volcanic origin and their climatic environment or the climatic environment of their immediate successors?

Organic Criteria

The inorganic record of past climate is only a portion of the story. It has generally been assumed that plants are the best indicators of climatic conditions, because of their relative immobility; but it is the nature of plant material to float, and plant remains may be transported a great distance, and even into regions of a radically different climate, before they find their final resting place. Again, the occurrence of aquatic plants in an arid region would be a surprise only to those who are unfamiliar with such regions. Each water-hole, seep, or spring is bordered with water-loving plants, and the water is frequently filled with a lusty growth. These are just the places where animals of an arid region would congregate and where their remains would be found when they finally mired down or were swept together after death by water currents. It would be strange error to interpret the climatic environment of a bison or a Pronghorn buck from the remains of an aquatic or semiaquatic vegetation which grew in the mire of their final resting place. How easily such an absurd mistake might be made is left to the imagination of every collector. One check is fairly certain if the collector knows how to handle his material;—the stomata of plants, either aquatic or terrestrial, of an arid region are all well protected, for there is one common control in the complex, and that is the drying winds. Even here the worker must remember that aquatic plants of stagnant water bodies have protected stomata.

It is natural that the author of this paper should recall instances in point from the remains of animals which dwelt on or near the flats of great streams or lakes, and one clear illustration of what may be learned from a study of the association of forms in the beds occurred in the experience of a recent collecting trip in the Triassic of western Texas. Here an abundance of remains of Phytosaurs and Stegocephalians was found. It is commonly assumed that these animals were at least semi-aquatic in habitat, but every collector is impressed with the fact the remains are not found in their natural habitat, and the interpretation of their environment has been uncertain. Last summer such forms were found in beds of hard clay and in beds of clay highly charged with gypsum, but frequently dissociated bones were found in old streams or current channels. In one place a bed of Unios was found associated with water-worn bones, and in such a channel a tooth of the genus *Ceratodus* was found, the first reported occurrence of this genus in the Triassic of North America, so far as the author has been able to determine. The climatic habitat of the Dipnoi is well known, and it is not to be doubted that the fossil forms were similar in habits to the surviving members of the group. We may, then, be pretty certain that the Phytosaurians and Stegocephalians of this locality lived in a climatic environment not unlike that of western Australia or the region of the Nile.

So it is that the student of paleogeography must know the physiography of the place and the time, the physiographic changes then at work, the original and altered character of the sediments, and the association of organic forms, and from these he can make an approximate, at least, determination of the climatic environment of the forms which he exhumes.

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METHODS OF DETERMINING THE RELATIONSHIPS OF MARINE INVERTEBRATE FOSSIL FAUNAS[1]

BY CHARLES SCHUCHERT[2]

(Read before the Paleontological Society December 29, 1920)

CONTENTS

THE PROBLEM STATED

When the question is asked, "How does one arrive at the conclusion that there are fossil faunas of Atlantic or Pacific, European, Asiatic, or South American origins?" we paleontologists are guided in our answer by the principles made use of by zoogeographers, the students of the continuous or discontinuous distribution of living animals. We know, for example, that at present humming-birds are to be found only in America, and chiefly in Central and South America; that mammals with solid horns or, better, with antlers are common to all the Northern Hemisphere, but that those with hollow horns, like the antelopes, are in greatest abundance in Africa south of the Sahara Desert. Africa is also known for its elephants, giraffes, rhinoceroses, hippopotami, lions, monkeys, and apes;

[1] Manuscript received by the Secretary of the Society March 3, 1921.
This paper is one of a series composing a "Symposium on criteria and methods employed in paleontological research."
[2] Read by F. B. Loomis.

and yet to the east of this land, on the great continental island of Madagascar, none of these mammals are present, but here we meet with an abundance of half-monkeys almost unrepresented in Africa. In the same way we know that in the North Pacific Ocean occur the fur-seals, while elsewhere are found the coarser-haired forms. Again, it is to the western Pacific that we go for nautilus, and to the Southern Hemisphere for penguins.

In our study of the causes that govern the geographic distribution of land life, we soon learn that it is very largely the physical environment of today that controls its localization. Temperature, moisture, and altitude above sealevel are the greater factors in the present control of organic distribution. The animals of the plains are not commonly found in the forests, while those of the mountains are often localized at elevations whose temperature is comparable with the latitudinal ones. Lydekker says, in his well known "Geographical History of Mammals": "An excellent instance of this is afforded by South America, where there are the open grassy plains of the Argentine, the dense tropical forests of Paraguay and Brazil, and the snow-clad heights of the Andes." Station is therefore very intimately connected with temperature, and is well illustrated by the distribution of the llama-like animals. Vicuñas and guanacos occur in the high Andes of Peru and Ecuador, but as we go farther south the guanaco only is found on the plains of southern Argentina and Patagonia, as well as on the island of Tierra del Fuego, at the sealevel. Being an animal which can live only in cold or temperate climates, it finds suitable conditions for its existence in tropical latitudes solely at a height of many thousands of feet, although farther south it is able to thrive at sealevel.

While temperature and moisture are the present dominant controls in the distribution of life, we learn from Alfred Russel Wallace that when an English naturalist is collecting in Japan "he sees so many familiar natural objects that he can hardly help fancying he is close to his home." And yet between the two countries there lies a continent with a wholly dissimilar flora and fauna. In this we get a hint of an intermediate area with a changed environment and a former continuous distribution of life now more or less restricted to western Europe and Japan. On the other hand, when Roosevelt was hunting in east-central Africa he was constantly reminded of the fact that the mammal world there had its closest relationship to those of other lands during the Pliocene. From these statements it appears that while the present distribution of plants and animals is largely controlled by temperature and moisture, yet back of these factors lies the greater one of geographic migrations, which in turn

has been largely determined by the climatic variations and the geologic changes of the past.

We all now know that geologic time is very, very long; and yet if the present geographic relations and topographic form, combined with the present climates, were to remain unchanged, it is thought that there would result almost no organic evolution. In other words, with the present environment retained and in the absence of the destructive tendencies of man, the organic world of today would continue almost unchanged. However, we geologists know that the earth's land surface will not long remain as it is today. The beautiful mountains flow piecemeal down the rivers into the seas and oceans, and thus extend the land areas, but periodically the land surfaces are raised high into the atmosphere, through whose agencies they were again and again destroyed. In consequence of these geologic changes, the climates and environments are repeatedly changed, and new routes of organic migration are established through the making of land bridges which unite the continents, or the latter become dismembered through down-sinkings of the land areas and thus open up new marine portals. In the one case, the life of the land spreads, while that of the oceans is localized; and in the other it is just the reverse condition which obtains.

Faunal Radiation

If all the species of a fauna were restricted to a radiation of at most one or two hundred miles, it would be exceedingly difficult to work out zoogeographic provinces and realms, and in stratigraphy the faunal realms probably could not be ascertained at all because of our present scattering paleontologic knowledge. Since, however, at least 5 per cent of living marine invertebrates have coastline ranges of from 5,000 to upward of 10,000 and even 15,000 miles, and since about 60 per cent of bottom-dwelling forms have ranges of between 2,000 and 3,000 miles, this variably wide distribution shows with certainty that the provinces and realms of the geologic past can also be ascertained.

It is this variable range of most of the marine invertebrates, and the additional fact that nearly all organisms are changing, some very slowly or seemingly not at all and others faster, that enable paleontologists to work out the times of their geologic origin, duration, and vanishing. Organic evolution is in the main progressive and in the direction of greater complexity, though a small per cent of the species are stationary or even regressive; and yet, in all this change, no species or genus is repeated in time. These facts indicate that fossils can be depended on in

the correlation of formations, and that the greater half of the faunas will radiate as far as the oceanic overlaps can spread over the continents.

Faunal Provinces and Realms

Early Paleozoic Provinces

Now let us turn to the marine invertebrate biotas and pick out some of the well ascertained faunas, to see how they group themselves into realms and provinces. At the very beginning of the Paleozoic is Lower Cambrian time, with its world-wide *Olenellus* assemblages. In addition to this genus, it is characterized by the perplexing Archæocyathinæ—reef-making cœlenterates, if such they are. In other words, we do not see at this time clearly differentiated faunal provinces, but only one realm common to all the oceans.

In the Middle Cambrian, however, the faunal story is very different. Now the world's marine waters are of two realms, a North Atlantic one, with the trilobite genus *Paradoxides,* and a North Pacific one, with several genera of large-tailed trilobites—the *Bathyuriscus* realm—common to western North America and China. These large-tailed trilobites do not get into North Atlantic waters until Upper Cambrian time.

In 1863 James Hall described the Upper Cambrian biotas of Wisconsin and Minnesota and acquainted us with many forms of trilobites, though in a rather fragmented condition. Later, more genera and species were added by other paleontologists, from Texas and the Rocky Mountains. For a long time, however, no faunal similarities with other continents were seen, because of the slight knowledge then at hand relating to the world's Cambrian assemblages. In 1883 the German paleontologist Dames described a few Cambrian trilobites collected in eastern China by Von Richthofen, and for the first time directed attention to a faunal resemblance with those of the upper Mississippi Valley. Since then large collections have been made in China by Blackwelder and Iddings for Walcott, and now it is clear that in Middle and Upper Cambrian times the North Pacific Ocean was a vast generating center of organic evolution. From it there spread great extensions of this ocean over eastern Asia and across the United States, and in 1915 Walcott tells us that many genera, either identical or closely related, are common to China, the Rocky Mountains, Texas, and the upper Mississippi Valley. Not only is seen here this common faunal expression, but even the sequence of Middle and Upper Cambrian biotas is alike on either side of the Pacific. One of the most rapid and widest dispersals of marine invertebrate lif

known to stratigraphy occurred during the early Ordovician in Canadian time—the almost world-wide distribution of the floating group of extinct graptolites closely related to hydroids and known as the *Phyllograptus-Tetragraptus* fauna. First made known by Hall between 1858 and 1865 from material collected near Quebec, Canada, it has been traced widely throughout the Appalachian geosyncline, Arkansas, Nevada, Utah, Newfoundland, Wales, Scandinavia, Belgium, France, Peru, Bolivia, Australia (Victoria), and southern New Zealand. Therefore, so far as the graptolite faunas are concerned, we again speak of them as cosmopolitan faunas.

DEVONIAN PROVINCES

Lower Devonian faunas.—We will now consider some of the Devonian faunas, since they are well known the world over, and, moreover, are replete with paleogeographic information. The Helderbergian faunas of New York and the central Appalachian region were first described by Hall in 1859, and now their total amounts to more than 450 species and varieties. The New York development continues its typical faunal expression through Pennsylvania south into southern Virginia, western Tennessee, and Missouri, into Oklahoma. Everywhere it is the life of a calcareous facies and southern in origin. To the northeast of New York, in the Saint Lawrence embayment, the Helderbergian formations take on a more sandy and muddy character, and their biotas, with a large element of North Atlantic species, are known from Montreal, Dalhousie, Gaspé, and Newfoundland.

Just as there are two Helderbergian provinces in North America, so in the same way there are two in Europe, and all four are of Atlantic origin. The southern development, the one in closest relationship with the New York Helderbergian, was long ago described by Barrande, and has since come to be known as the Konieprussian assemblage, while to the north of Bohemia and the Pontian old land are the German equivalents now called the Gedinnian faunas.

These oldest Devonian faunas are characterized at first by their many Silurian hold-overs, but it is evident that certain of these elements soon begin a rapid evolution into new species and genera that are heralders of a new period of time and a new provincial assemblage. Our correlation values here are, among the brachiopods, the rise of many new strophomenids, rhynchonellids, spire-bearers, and primitive terebratulids; among the gastropods, the great outburst of capulids, most of which attain to large size; among the cephalopods, the rise of small goniatites; and

among the trilobites, the evolution among the *Dalmanites* (in *Hausmannia, Corycephalus, Probolium,* and *Odontocheile*), the lichadids (*Dicranurus*), and the phacopids. Since these faunas are known on either side of the Atlantic Ocean, or, better, Poseidon, we speak of them as of the Atlantic realm. There is also a Pacific realm of this time, but as yet its faunal elements are known only in Nevada.

Austral Devonian realm.—To understand correctly the very interesting higher Lower Devonian faunas, we will begin our studies in the high Andes of Bolivia. Here d'Orbigny for the first time in 1842 described a few fossils, correctly referring them to the Devonian, and further additions were made by Morris and Sharpe in 1846, and by Salter in 1861. Finally the greatest additions to these faunas were made by Steinmann and his students A. Ulrich (1892) and Knod (1908). Now we know a fauna of more than 100 forms that occurs through a thickness of about 2,300 feet of gray or yellow micaceous well bedded sandstones and dark shales. Its age is of the higher Lower Devonian, comparable with the Oriskanian of the United States and the Taunusian and Coblenzian of Germany.

Another center of geologic endeavor in South America was started in 1874 by Professor Hartt, of Cornell University, in his explorations of the Amazon Valley. His field-work on the Devonian of Brazil was further extended by O. A. Derby between 1878 and 1890, and the faunas have been described by Rathbun (1874, 1878), Katzer (1896 to 1903), and, above all, by J. M. Clarke (1890 to 1913). The Lower Devonian faunas of Brazil amount to about 75 species; for the whole of South America, however, including the Falkland Islands, the total is about 240 forms, and most of its elements have been modernized by Clarke.

The higher Lower Devonian faunas are now known from the Andean region of Bolivia, Peru, and Argentina; from the Amazon Valley along the rivers of Maecuru, Curuá, and Ereré; from the Brazilian States of Paraná and Matto Grosso, and from the Falkland Islands. A very similar fauna is also known in the Bokkeveld formation of southeast Africa and in the Sahara desert at Tasilé. It represents the *Leptocœlia flabellites* realm of the higher Lower Devonian, the austral seas that overlapped on the old land Gondwana. These austral assemblages are characterized by the almost total absence of corals, echinoderms, bryozoans, and cephalopods, with a marked development of gastropods of the *Bellerophon* and capulid types, an abundance of *Conularia,* and, above all, a great variety of peculiar brachiopods. The characteristic genera of the last-named class are *Hipparionyx,* very large flat *Chonetes, Eatonia, Tropidoleptus*

carinatus, Leptocœlia flabellites, Spirifer of the *antarcticus* group, and primitive but large terebratulids like *Rensselœria, Scaphiocœlia,* etcetera.

All of these local faunas have a common generic and specific development, and because this expression is quite unlike that of the same age in North America and Europe, Clarke has distinguished them as of the austral Lower Devonian realm, "as an emphatic distinction from the boreal faunas" of the Northern Hemisphere.

When we examine into the geographic relationships of these various local faunas of the austral realm, it is seen that those of Bolivia, Peru, and Argentina are very similar and more closely related to those of Paraná and Matto Grosso. Those of northern Brazil, however, are quite different, and, even though there is here a mixed boreal and austral development, on the whole the Amazonian Devonian is clearly of the austral realm. On the other hand, the fauna of the Falklands is already more closely related to those of South Africa, even though they are more than 4,000 miles away, while it is only 1,500 to 2,000 miles to the nearest South American assemblage.

The continent Gondwana.—Now let us look into the paleogeographic significance of these austral Lower Devonian faunas. The geography of the places recited shows them to lie on or toward the margins of an extensive transverse continent formerly extending from western South America across Brazil and the medial or tropical Atlantic Ocean to eastern Africa, a land that has long been known as Gondwana. If there had been in Devonian times a tropical Atlantic like that of today, the African faunas would be very dissimilar from those of South America, and there would have been developed two austral faunal realms instead of one, and this through isolation and shallow-water migrations around two continents instead of one.

Nevertheless, to make sure of our conclusions that Gondwana across the Atlantic is a fact, and the cause for the existence of but one austral Lower Devonian realm, we get further and complete verification in the distribution of the marine Pennsylvanian, and especially the Jurassic and Comanchean, faunas of western South America. All of these assemblages constantly have forms in common with the Mediterranean countries, and chiefly with their southern or African extensions, while but very few forms indeed are in common with the Indian Ocean. Hence we see that during these times there was no equatorial Atlantic, but, on the contrary, that there was a land here along whose northern and western strands the shallow-water life migrated back and forth. All of this was plain to the great Neumayr, who as early as 1885 traced out the distribution of the

Jurassic ammonites and followed the Mediterranean forms all along t western coast of South America. It was he who accordingly postulate Gondwana and illustrated it on his widely known paleogeographic ma of the world's continents during Jurassic time. Finally we may add tha it is this continent of Gondwana that has most of the early Permia tillites widely distributed over it, and that it was the generating an dispersing land for the *Glossopteris-Gangamopteris* flora, which also at tained peninsular India, Australia, and even Antarctica. Later, in Per mian time, this flora reached the Northern Hemisphere and gave rise i the main to the early Mesozoic plant worlds.

Boreal Devonian realm.—Just as there is an austral late Lower De vonian realm, so there is a boreal one in eastern North America an western Europe. The faunal developments in the two provinces of thi boreal realm are, however, not vastly different, since many of the form were able to pass to and fro along the easy migration route of northen Gondwana into the Mediterranean lands and from here along the shore leading into northern Europe. Thence the Coblenzian faunas of Ger many and England spread as easily westward along the shore of Eri into the Saint Lawrence embayment of the North Atlantic, or Poseidon where Clarke has described these biotas in Americanized form fron Gaspé, Percé, Dalhousie, and Maine. On the other hand, the route o migration from South America direct to North America was far less easy for the two continents were long separated by the deep, mediterranean like waters of which the present Caribbean is a modified and reduced re mainder. We now know, moreover, that the Oriskanian faunas of Gaspe spread south through the Appalachian geosyncline into western Tennesse and Missouri and are to be expected in Arkansas and even in Oklahoma While the Helderbergian faunas of Atlantic origin came up the Gulf o Mexico embayment, nothing of the sort occurred during the Oriskanian for there was land here north of Alabama until early in the Middle De vonian. Then this waterway was again opened and the Camden faunas with a South American impress, spread into western Tennessee and south ern Illinois.

The Middle Devonian faunas of North America east of the Mississip River have long been known as constituting an independent but great restricted faunal realm. Kayser named this the American province, a it is a generating and dispersing center, but receives most of its migran chief among them the tabulate corals and the tetracorals, through t Saint Lawrence portal, while the least number arrive by way of the G of Mexico embayment.

Now we come to the most extensive of all Devonian faunal realms, the Euro-Asiatic one of Upper Devonian time. This is at first characterized by the brachiopods *Stringocephalus burtini, Hypothyris,* and *Gypidula,* and by a series of goniatites. These Upper Devonian assemblages have a common expression throughout the Northern Hemisphere, with the exception of America roughly east of the Mississippi River. Here the Middle Devonian Hamilton fauna, somewhat modified, persists into the Ithaca biota of early Upper Devonian time, but soon this marine region goes over into a great bay with sluggish waters depositing black shales to the west of the great sandstone delta of the Appalachian geosyncline. But, even under these adverse conditions, there are received pulsations of the *Hypothyris cuboides* and *Spirifer disjunctus* faunas, which appear, however, to have come from western Europe down the Saint Lawrence portal, battling for possession of the Appalachian sea east of the Ozark-Kankakee axis. On the other hand, the more typical Euro-Asiatic faunas spread from the Arctic down the Mackenzie Valley into Minnesota, Iowa, and Michigan, and during short intervals the *Spirifer hungerfordi* faunas were able to penetrate into central New York.

Summation

In summary, we see that the faunal provinces and realms are marked at times by identical species of very wide distribution, but more often by generic and family developments spreading throughout the shallow seaways for some thousands of miles, or as far as they can find a similar environment. These entities are prevented from spreading everywhere, not so much by temperature, but mainly by barrier lands and by deep oceans of wide extent. Even so, some of the ground-attached, shallow-water invertebrates succeed in establishing themselves directly across the oceans; but this is possible only among those that have long-lived floating larvæ, which are several weeks in developing before they are compelled to seek the marine bottoms. As a rule, the larvæ of bottom-living invertebrates are free-floating and are carried about by the currents for only a few days; consequently but few of them are able to spread and mature beyond the range of the shallow seas of their birth.

From the evidence recited it will also be seen that provinces and realms are characterized now by one and now by another class of invertebrates or by a group of them. At one time the dominating entities are of the attached bottom life, like the brachiopods; at another they are the sluggishly crawling kinds of gastropods and bivalves, and at yet other times the more active trilobites or cephalopods. And so it has always been:

some forms of life rise quickly into the ascendancy, grow to large size and prolific numbers, and dominate their environment. Then the fickle environment changes with the ever-changing earth's surface, and during these times of marked alterations the once dominant species and genera die out or evolve into new races, while some of the less significant forms take the ascendancy and quickly come to be the rulers of their day and domain—the guiding forms for the interpreting stratigrapher.

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CRITERIA FOR SPECIES, PHYLOGENIES, AND FAUNAS OF TRILOBITES [1]

BY PERCY E. RAYMOND [2]

(*Read before the Paleontological Society December 29, 1920*)

CONTENTS

INTRODUCTION

The describer of trilobites has an advantage over the student of Brachiopoda, Mollusca, and various other invertebrates in that the animals with which he deals have more parts, and hence present more combinations of characteristics which may be used in the discrimination of species. On the other hand, he suffers from the disadvantage that his specimens are apt to be dismembered, and very many species are known from fragments only. Due, perhaps, to this latter contingency, trilobitists have, as a rule, been rather conservative, and it is only within the last few years that an era of nice distinctions has been inaugurated. Compared with the number of individual specimens, the number of species and genera of trilobites still remains few, but bids fair to be increased rapidly in the next decade or two.

CHARACTERISTICS OF THE BODY

The body of the trilobite is doubly tripartite, but the longitudinal division which is characteristic of the subclass is seldom of specific value.

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This paper is one of a series composing a "Symposium on criteria and methods employed in paleontological research."

[2] Read by R. S. Bassler.

since the proportion of the width of the axial to the lateral lobes is usually constant in the various genera. The division transversely into cephalon, thorax, and pygidium is subject to much more variation, and the relative lengths of the three portions are very frequently used in separating species.

The total number of segments in the trunk being highly variable, those trilobites which have many in the thorax usually having few in the pygidium and *vice versa,* it naturally follows that some uncertainty exists as to the taxonomic value of the number in either. The number in the thorax is constant in some families, as in the Asaphidæ and Phacopidiæ, but is variable in many others, and even in some species; so that, while it is occasionally cited in specific descriptions, it is only in connection with more important features.

Characteristics of the Cephalon

The cephalon is the part of the trilobite most desired by the taxonomist, for it exhibits the features which are of the greatest value in classification. It is quite natural that this should be so, for this is ontogenetically the oldest part, and in certain respects it is the fixed and stable portion of the body, to which the trunk is a more or less flexible appendage. External environment will affect more directly the movable thorax and pygidium than the more solid anterior shield. It is, in fact, found that cephala are generally less variable than pygidia, though many specific characteristics are drawn from the head.

Since the time of Salter and Barrande, the major characteristics used in classification have been those of the cephalon, but it remained for Beecher to show the value of the facial sutures, and so put in logical order the families already in use. As is well known, Beecher used Hyatt's method of inferring relationship from the history revealed by ontogeny, and made it possible, from the inspection of a cephalon alone, to place any particular trilobite in one of the three orders which he proposed. What little work has been done on phylogenies within the group has been based on ontogeny, worked out by Barrande, Matthew, Beecher, Ford, and Walcott, as interpreted by Beecher.

While the position of the facial suture designates the order and the position in the order of the family, the families themselves are not based on the facial suture, or even on the structure of the head alone, but usually on a number of characteristics drawn from all parts of the body. As now defined, they are, in fact, aggregates of more or less like genera and are in many instances hard to define. This, though bothersome to the taxonomist, is an exceedingly satisfactory state of things, since it shows

that there is a gradation from one group to another, and that material is gradually accumulating that will permit the evolution of the subclass to be followed out. Genera, as they are now coming to be limited, are merely small aggregates of similar species, and various men hold widely different ideas as to the latitude allowable in a generic group.

Generic characteristics are generally drawn from the features of the whole body, if all parts are known; otherwise from the head. It is true that a very few genera have been based on pygidia alone, through force of lack of material, but not from choice. It is often impossible to determine a genus from the latter shield alone, and in cases of parallelism the distinguishing characteristics are usually to be found on the cephalon. A few genera have been based in part on the form of the thorax; but, while that may be diagnostic within a genus, it is not often relied on entirely.

Specific value is usually given to such features of the cephalon as the proportion of length to breadth of both the whole shield and of the glabella; sometimes to the position of the eyes, although this is often of higher rank; to the length and shape of the genal spines; to the brim, its extent, profile, and breadth; the convexity of the glabella and the condition of its furrows; the position and characteristics of any spines or pustules; and to the pattern of any ornamentation that may be present. All these things have different values in different groups, and, so far as possible, combinations of characteristics are chosen. At the present time, trilobites are usually described in considerable detail, for one is never quite sure which are the features which are going to be of most use. The short descriptions in Latin given by some of the earlier writers are frequently of no value at all, as they may apply to a number of species now known.

Characteristics of the ventral Side and Pygidium

The ventral side of the body has never, so far as I know, been used in discriminating species. The extent and form of the doublure has in a few cases afforded generic distinctions; the shape of the epistoma is, in many cases, of family value, and the hypostoma often enables one to recognize a genus or, if not that, a family. The appendages, even if they were commonly well preserved, would probably be of little help in making other than the larger subdivisions, for they seem to have been generalized and very similar in unlike trilobites.

The pygidium is more used in making specific distinctions than any other part of the body. In most cases the minor details of the conformation of this shield are so variable that the whole combination has low

taxonomic rank. The proportion of length to breadth is almost always constant in small groups and has been used to advantage in making species in various genera, particularly of smooth trilobites, which lack other striking features. Correlated with this is the number of segments, which is seldom fixed and may or may not be of specific value. In some genera, where there is wide variation in this particular, a difference of five or six will pass unnoticed, while in others new species have been erected because of one more or less than the usual number. The rings on the axial lobe represent the true number of segments in this shield, and there are usually less ribs on the pleural than rings on the axial lobe. The number of ribs is frequently of specific importance, as is also their length, prominence, furrows, and ornamentation. The width of the border should also be noted, and while its presence or absence may be of generic importance, its width, outline, and profile often serve to limit a species. When spines or pustules are present, either on the margin or on any portion of the upper surface, their position, size, curvature, arrangement, and number almost always present combinations of specific value.

Summary

It is obvious from the above outline that the trilobites do not lend themselves readily to an artificial classification, and that there are no uniform "generic" or "specific" characteristics. It can not be said that an ideal and complete classification has yet been reached, and only when a fuller understanding of the structure and ancestry of the whole group is attained will there come full realization of the relative importance of the various parts of the anatomy. We are, in our descriptions, still struggling somewhat blindly toward the goal.

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CRITERIA FOR DETERMINATION OF CLIMATE BY MEANS OF FOSSIL PLANTS[1]

BY F. H. KNOWLTON[2]

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CONTENTS

INTRODUCTION

After some differences in concept, the term climate has come to be applied to the atmospheric conditions of weather normal to a given locality or region. Although there are very considerable areas of the earth's surface that exhibit similar climatic conditions, it needs little reflection to demonstrate that the climate of the earth at the present day is by no means uniform throughout. If, for instance, we travel either north or south from the equator we pass successively through a so-called torrid zone, a temperate zone, and, in polar lands, a frigid zone, each with minor but distinctive modifications. In other words, the present distribution of climate is zonal. But it has been demonstrated with what seems a reasonable degree of certainty that the climates of the past were distinctly non-zonal in their distribution—that is, ancient climates appear to have been practically uniform for vast periods of time and of practically world-wide extent. The object of the present paper is to set forth the criteria by which this conclusion is reached.

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This paper is one of a series composing a "Symposium on criteria and methods employed in paleontological research."
[2] Read by R. S. Bassler.

Fossil plants have long been called the thermometers of the past; in this light they have been regarded by most students as more trustworthy guides than fossil animals, though when correctly interpreted there is usually little discordance in the two lines of evidence. It is easy to see why plants may furnish more reliable data than animals. A great majority of animals are endowed at some stage of their life cycle with the power of locomotion, which enables them to move about more or less freely in response to various external forces, perhaps the most important of which is that of the climatic environment. When, for whatever reason, the conditions become unfavorable the animal is more or less free to change its habitat, but the plant is largely fixed in position and when stresses come must usually succumb.

Stabilization of Temperatures for Plants and Animals

Before presenting the paleobotanical criteria for interpreting ancient climates, it is pertinent to call attention to the fact that since at least Algonkian time terrestrial temperature must have been stabilized between relatively narrow limits, else life could not have been continuous, as we have every reason to believe it has been.

The vital processes in plants are practically suspended when the temperature falls below 32° Fahrenheit (0° centigrade), though during their resting stage many plants, especially in polar lands, are accustomed to endure a temperature of —70° Fahrenheit or even lower. The opposite extreme is shown by certain simple types of algæ that thrive in waters of hot springs under a temperature approximating 200° Fahrenheit, and there is a very considerable diversity of algal life in thermal springs with temperatures ranging between 140° Fahrenheit and 180° Fahrenheit. Certain bacteria, it is known, can, when in an encysted stage, withstand temperatures ranging between +120° centigrade and —200° centigrade, or even —250° centigrade for short periods. The optimum temperature for plant life, however, is usually between 22° and 37° centigrade (71° to 98° Fahrenheit).

The extremes of temperature between which animal life is possible are apparently less than for plants. No known animal finds a congenial habitat, either aquatic or terrestrial, that has a permanent temperature of 200° Fahrenheit.

From this discussion it appears that the range of biologic toleration can hardly exceed 200° Fahrenheit—that is to say, a permanent raising of terrestrial temperature above 200° Fahrenheit or lowering it below 32° Fahrenheit would have inhibited life on this globe.

CRITERIA FOR INTERPRETATION OF CLIMATIC CONDITIONS

In seeking to ascertain the bearing of the fossil floras on the climatic conditions that obtained at the time they were living, it is desirable to set forth the criteria that must form the basis of such judgment. In drawing conclusions from individual organisms in an inquiry of this kind, dependence must, of course, be placed on our knowledge of the present-day requirements of similar species, and the results must always be subject to possibility of error from two sources: first, from the incorrect placing biologically of the organism, and, second, from the fact that its requirements in past geologic time may not have been the same as those which now dominate the life activities of its supposed analogue. However, when all or a very considerable proportion of the elements of a flora appear to point in the same direction, the liability to serious error is minimized if not eliminated.

An outline of the criteria most relied on in the interpretation of climatic conditions has been so succinctly stated by White in his paper on the "Origin of coal" that I venture to quote it entire:

"During the times of deposition of most of the principal coal groups the climate has been characterized by (1) general mildness of temperature, approaching in most cases tropical or subtropical; (2) conspicuous equability or approximation to uniformity of climatic conditions, which, with a few exceptions, appear to have lacked cold winters or severe frosts; (3) a generally high humidity, the rainfall being from moderately heavy to very heavy and fairly well distributed through the year, though in many cases there is evidence of the occurrence of dry periods, which, however, seem ordinarily to have been comparatively short and not severe; (4) an amazingly wide geographical distribution of these genial and equable climates, which occurred seemingly in almost uniform development simultaneously in the high and in the low latitudes of both the Northern and the Southern Hemispheres. This shows either that the essentially uniform climatic conditions were truly extraordinary in geographic extent, with little regard to modern climatic zones, or that the formation of coal was mainly confined to the areas of the above-prescribed climatic environment.

"The principal criteria as to climate offered by the fossil plant remains, preserved either in the coal or in the enveloping shales and sandstones, and serving as a basis for the conclusions stated above, may be summarized as follows:

"1. Relative abundance or luxuriance and large size of terrestrial vegetation—that is, rankness of growth—indicating favorable conditions of temperature, humidity, etcetera.

"2. Character, condition, and amount of the land-plant material preserved as coal or carbonized in the rocks. The formation of xyloid coal of the ordinary types, composed mainly of subaerial vascular plant remains, indicates humidity. In regions of cool temperature the humidity required for the formation of peat—the initial state of coal—is moderate; in warmer climates,

where decay is more rapid, not only must the humidity be greatly increased in order to provide the necessary wetness to retard decomposition, but there must be no long dry season of the year for the too great reduction of the water cover. The observations of peat formation at the present day in tropical climates show that in order to permit the deposition of peat the rainfall must be both very heavy and fairly well distributed through the entire year.

"3. Great radial distribution, seemingly over the greater part of the earth, and especially over wide ranges of latitude, of identical species and genera in characteristic association, indicating the extension of approximately uniform climatic conditions in these regions. Floras identical, or essentially identical, in remote or detached regions can owe their identity to no other cause than approximately continuity of the environment, whether that continuity is geographic or chronographic. Conversely, migration of a flora without change is possible only through regions of essentially identical environmental conditions. Illustrations are found in the Carboniferous, Triassic, Jurassic, and Lower Cretaceous floras, and even to a remarkable degree in the Upper Cretaceous and Tertiary floras.

"4. Presence of types known to be adapted to or confined to the warm temperatures or moist climatic conditions of the present day, types that though now extinct once lived in association with other types of ascertained tropical or humid habitats, and types whose descendants or nearest surviving relatives are characteristic of warm climates. Examples are cycadalean types in Carboniferous, Triassic, Jurassic, Cretaceous, and, finally, in the Oligocene, in association, since the Trias, with living tropical and subtropical genera or families; the presence of tree ferns in nearly all periods of coal formation; palms, cinnamon trees, climbing ferns, and many other tropical or subtropical types in the Upper Cretaceous; and breadfruit-trees, etcetera, in the Lower Tertiary.

"5. Structures of the plants themselves. Features showing rapidity of growth—that is, abundant rainfall, mild or warm temperatures, etcetera—conditions favorable to rapid growth:

"(*a*) Very large size of the cells, many with thin walls, and large intercellular spaces, indicating rapid growth and abundant moisture, noticeable in the woods found in and with most coal.

"(*b*) Large size of fronds and leaves, indicating conditions favorable to growth and, at present, characteristic of moist tropical habitats.

"(*c*) Frequency of lacinate or much-dissected, drooping fronds and pendent branches or twigs seemingly adapted to facilitate the run-off of rain, and protection of the stomata in grooves on the under sides of many leaves, as in the Lepidophytes of the Carboniferous.

"(*d*) Smoothness of bark, which is often thick, pointing toward warm, humid swamps.

"(*e*) Absence of growth rings in the woods of the older coal formations, showing climatic conditions favorable to practically uninterrupted growth, and the absence of long dry seasons or winter frost. Such absence of rings, when noted in all the associated types, plainly shows the approximation to equability of climate.

"(*f*) Wide occurrence in the Paleozoic coal fields of heterospory, requiring prevalent swamp conditions; and the occurrence of delayed fertilization and of devices for seed flotation.

"(g) The development of subaerial roots in many of the types.

"6. A circumstance that may be observed in most coal fields in proof of abundant rainfall at the time of coal formation is the continuity of many coal benches or strata from one hollow or pan over the intervening shoal or sand bar into the next pan or along the slight gradients of the baselevels, a circumstance impossible except with sufficient rainfall to saturate the vegetal cover and maintain a ground-water table of retarded drainage held by the obstructing vegetation.

"7. Two other interesting lines of evidence for the warm climate of the Carboniferous are seen, as pointed out by Potonie, in (a) the development of more flowers and fruits on the lower parts of stems and branches, as in Ulodendron, Sigillaria, and many Calamariæ, a characteristic of dense tropical forests at the present time, and (b) the presence in many ferns of Aphlebiæ which today are unknown except in tropical types."

Steps in Study of climatic Criteria

Although the foregoing account was drawn up especially to cover conditions during the deposition of the great coal deposits, and more particularly the Paleozoic coals, it nevertheless applies with approximately equal force to all horizons. As we ascend in the geologic column, plants become increasingly similar to existing plants until, in the late Pleistocene, they largely merge with the present flora. When, for example, a flora in the Mesozoic or early Cenozoic is interrogated as to its probable bearing on the climatic conditions under which it grew, the first step is the identification—as complete as possible—of the elements comprising this flora. It is then compared as closely as possible with its obviously nearest living relations, and from a study of the moisture and temperature requirements of these living analogues a conclusion is reached as to the probably similar demand of the ancestral forms. If this judgment was based on only one or two forms, the possibility for erroneous interpretation would be increased; but when there are a considerable number all pointing in the same direction, the probability of falling into error is certainly reduced if not eliminated.

Examples of the Application of climatic Criteria

A number of examples may be cited. The Jurassic flora enjoyed in many respects the most marvelous distribution of any known flora, either living or fossil. It is known to range from Franz Josef Land, 82° north, to Hope Bay, Graham Land, 63° south, and from extreme western Alaska entirely around the earth to eastern Australia, or through more than 155 degrees of latitude and more than 230 degrees of longitude. Throughout this vast, practically world-wide, area there is a remarkable uniformity of distribution—that is, not only in individual species widely spread, but

a considerable assemblage of species. This distribution shows conclusively that there was not only free communication between the Eastern and Western Hemispheres, but also between the Northern and Southern Hemispheres, and, as none of the Jurassic plants is known to possess any peculiar mechanism for dispersal, it is apparently clear that there must have been a continuous or practically continuous land connection throughout this vast area. It is also evident that this wide distribution could only have been possible under very uniform climatic conditions. Such a distribution would be utterly impossible under the present zonally disposed climates.

Without attempting to present a complete analysis of this flora (for which see my paper, "Evolution of geologic climate"), the conclusion is reached that the presence of luxuriant ferns, many of them tree-ferns, equisetums of large size, cycads, and conifers, the descendants of which are now found in warm lands, all point to a moist, warm, probably subtropical climate.

The Upper Cretaceous Atane flora of Greenland may be briefly considered. This flora ranges from Greenland along the Atlantic Coastal Plain and Gulf region to Texas with but little change, and the Dakota flora spread with practically no change from Minnesota, Nebraska, and Kansas to Argentina. The inference to be drawn from these facts is that during Upper Cretaceous time the temperature conditions were very uniform over the greater part of the earth's surface, extending from at least 72° north in Greenland to at least 60° south in Argentina, with the probability that it was practically world-wide. A study of these floras reveals very little evidence of deciduous habits, which implies an uninterrupted growing season and an abundant, or at least adequate, supply of moisture, well distributed throughout the year. The coal deposits of Upper Cretaceous time also imply widespread and long-continued swamp or marsh conditions.

In the Atane flora there are such genera or Artocarpus (breadfruit-tree), Cinnamomum, Laurus, Pseudocycas, Aralia, Panax, Cyathea, Gleichenia, Widdringtonites, etcetera, which are largely tropical or subtropical in distribution. Associated with them are such genera as Acer, Asplenium, Cassia, Cissites, Diospyros, Hedera, Ilex, Magnolia, Myrsine, Paliurus, Pinus, Pteris, Quercus, Sapindus, Selaginella, etcetera, which while having more or less representation in temperate regions many have representatives in warm temperature and even subtropical regions. From this it seems safe to conclude that the climate of Greenland during Atane time could not have been cooler than warm temperate, and when we consider the presence of breadfruit-trees, figs, cinnamon trees, tree-ferns, etcetera, it might well have been subtropical.

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IMPRESSIONS MADE BY BUBBLES, RAIN-DROPS, AND OTHER AGENCIES[1]

BY W. H. TWENHOFEL

(Presented before the Society December 28, 1920)

CONTENTS

INTRODUCTION

Geologic literature abounds with statements relating to the occurrence of rain-drop impressions, but in few instances is information given as to the appearance of the marks which are so designated. When pitlike structures have been found, they have generally been ascribed to rain-drops, and it has been concluded that the containing deposits were those of a region over which at times there was no water. Notes of caution have occasionally appeared, but they do not appear to have been widely read.[2]

The best paper on the subject of rain-drop impressions with which the writer is familiar is that of Lyell, in which are described "rain-marks of the Recent, Triassic, and Carboniferous periods." [3] This paper describes

[1] Revised manuscript received by the Secretary of the Society May 3, 1921.
[2] Desor: Edinbourgh New Phil. Jour. for 1850, p. 246, quoted by Lyell.
[3] Charles Lyell: Jour. Geol. Soc. London, vol. vii, 1851, pp. 238-247.

recent and fossil rain-drop impressions and gives some criteria by which they may be recognized. Some data are also given on impressions from the Triassic rocks of the Newark series, which are ascribed to hail. Meunier has shown how rain-drop impressions may be artificially developed.[4]

At different times attempts have been made in the Sedimentation Laboratory of the University of Wisconsin to find out in how many ways impressions could be made which resemble rain-drop impressions and might be mistaken for such. It has been learned that, in addition to pits made by organisms, these develop in nature in at least nine different ways, namely: (1) impressions made by rain-drops, (2) impressions made by hail, (3) drip impressions, (4) spray and splash impressions, (5) impressions made by bubbles floating in shallow water and becoming anchored to the bottom because of mud settling on their outer surfaces, (6) impressions made by bubbles formed on the surface of an area overflooded, the bubbles developing from the air pushed out of the earth being submerged and held to the bottom by the settling sediment, (7) impressions made by the rising and falling of bubbles over very shallow waters, (8) impressions made by bubbles arising from the decay of organic matter contained in mud and making their way to its surface, where they either burst or remain attached, and (9) the small pit and mound structures described by Kindle.[5] Each of these nine types of impressions will be described in detail.

Impressions made by Rain-drops

In the writer's experiments rain-drop impressions were made artificially by throwing water from a spray to a height of about ten feet above the tray in which was placed the mud intended to receive the impressions. The mud used consisted of mixed lake marl and glacial clay and was made of a consistency to receive and retain impressions. The marks developed are identical in appearance with those made by actual rain. The impressions consist of circular to elliptical pits surrounded by slightly elevated and somewhat ragged rims. The surfaces of the depressions are rough, with the small elevations of sufficient magnitude to be readily seen with the eye. The rims are slightly more elevated and the depressions somewhat deeper on the sides toward which the falling drops were directed. The depth of the depressions vary with the dimensions of the

[4] Stanislas Meunier: Géologie Expérimentale, Bibliothéque Scientifique Internationale, 1899, p. 38.

[5] E. M. Kindle: Small pit and mound structures developed during sedimentation. Geol. Mag., December 6, 1916, vol. III, pp. 542-547.

drops which made them, the force with which the drops fell, and the softness of the mud. If the mud be very soft, it flows and the impressions become obliterated or greatly reduced. About one-tenth of an inch ap-

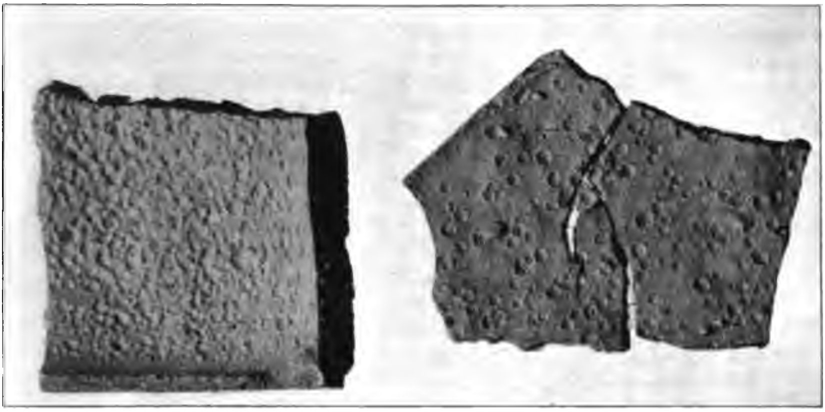

FIGURE 1.—*Impressions made by Rain-drops*

On the left coalescing pits formed by many drops. On the right isolated impressions.

FIGURE 2.—*Rain-drop Impressions made on wet Sand*

pears to be the maximum depth. The marginal elevations vary, due to the same factors which control the depths of the depressions. About one-tenth of an inch appears to be the maximum height. The diameters of the depressions vary from about one-half an inch to that of a pin-head

or even less (figure 1). After a rain of a few minutes a mud su
becomes thoroughly sculptured through the presence of a multiplicit
coalescing pits (figure 1). Further rain covers the surface with m
water, previous impressions are destroyed, and there is no possibilit
their being made until the water leaves the surface.

FIGURE 3.—*Impressions made by artificial Hail*

Rain-drop impressions are also made in sand. If wet sand be str
by rain-drops, impressions are made and continue to be made until
sand becomes covered with water. These depressions are similar to t
made in mud, except that the raised rims are not so sharp or so wel
fined (figure 2). Pits are also made in dry sand and dust by rain-d
but the margins are less sharp than where the sand or mud is wet.
ing out of the sands tends to make the depressions and the margina
vations less pronounced, and a little wind will altogether obliterate

Hail Impressions

In the experimental work of the writer, spherical and elliptical pieces of ice were projected with considerable initial velocity from a height of about twelve feet into a tray filled with mud of the same character as that used for making the rain-drop impressions. The mud prepared was given considerable consistency, as it was found that in very soft and fluid mud the hailstones became buried and the depressions ultimately nearly disappeared. Hail impressions are deeper and have higher margins than are those made by rain-drops. The depressions are of the shapes of the pieces of ice in cases where these descend perpendicularly. If the hailstones have horizontal components in their descent, the depressions produced are of elliptical outlines and are deeper and have higher rims on those sides toward which the pieces of ice were directed. As in the rain-drop impressions, the depths of the depressions and the heights of the rims are controlled by the sizes of the hailstones, the force with which they fall, and the character of the mud. Impressions of this origin can also become of far greater diameters than is the case for rain-drop impressions, as hailstones the size of a pigeon egg are known to be quite common, and in a big hailstorm in Kansas the past summer hailstones in excess of half-pound weight were reported. It is known that impressions of at least a couple of inches in diameter have thus been formed. It is probable that large hailstones would produce impressions in muds overlain by shallow water, although under such conditions considerable mud is stirred up which on settling reduces the depths of the holes.

Drip Impressions

Drip impressions, in the writer's observations, appear to be more common than are those made by rain-drops. The beginning of a rain will fall in most cases on dry ground, on which it is well nigh impossible to form impressions. Continued rain destroys those which were formed in the beginning. The closing of a rain rarely makes impressions, as the mud flats are then very soft and are more or less covered with water, making the formation of impressions essentially impossible. Dripping from trees continues for a long time after rain has ceased falling, and the falling drops at some time find the mud in an extremely favorable condition for receiving impressions.

Drip impressions are similar to rain-drop impressions, but the maximum dimensions as well as the average dimensions appear to be larger. As a rule, the drop falls without a horizontal component, so that the rim

around the depression is symmetrical. A feature seen in d
made after a rain in Dubois County, Indiana, on July 17,
falling from an elm tree, was the presence in the center o
sions of a small cone about equal in height to the depth of
This feature the writer has not seen in rain-drop impress
been able to produce it in drip impressions made in the la
thought that it may
to the drops fallin
not as spheres, with
of less thickness in t
on the peripheries.
sions had ragged r
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presence of the cen
similar to rain-dro
They varied in
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sions approximating
mensions than the
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It is obvious that
this origin general
presence of large
hence could not ha
sively developed be
tion of such. Thei
currence should, th
expected in strata o
Devonian or possibl
but impressions made by drops falling from overhanging
must have been made throughout geologic time.

FIGURE 4.—*Drip Impressions in soft Mud*

SPRAY AND SPLASH IMPRESSIONS

Spray and splash impressions are produced where w
spray from the waves against muddy or sandy surfaces or
splashed by falling objects. The former may be seen on th
of almost any body of water, while the latter are readi
throwing rocks into bodies of water which have muddy sl

pressions do not appear to be different from those made by rain-drops, so far as shapes are concerned, but there is great variation in diameter.

If drip, rain, hail, and spray and splash impressions be made in extremely soft mud, the result will be flowage of mud into the depressions, and they may be obliterated or greatly reduced in depth.

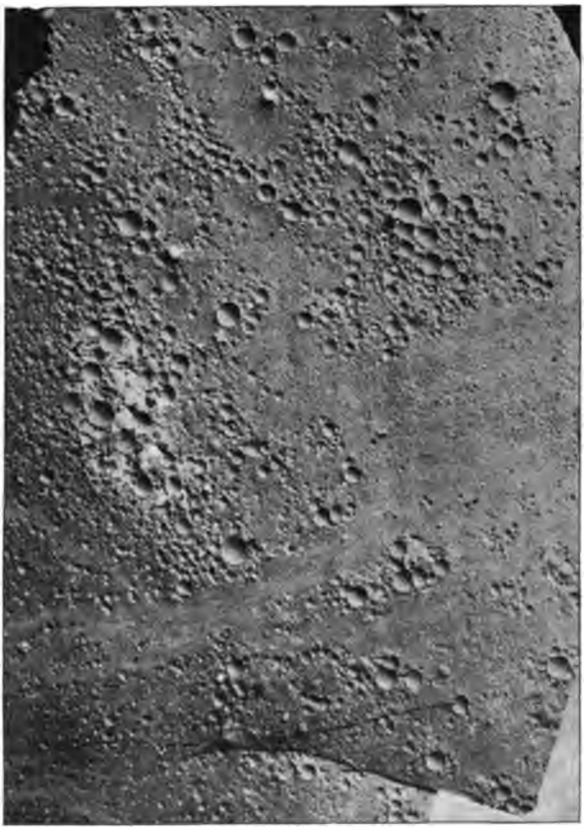

FIGURE 5.—*Impressions made by stranded Bubbles*

IMPRESSIONS MADE BY ANCHORED BUBBLES

Bubble impressions are made by bubbles floating and becoming anchored to the bottom through sediment becoming attached to the films or stranding in shallow water. In the experiments of the writer the impressions so made varied in diameter from very small to about 7 millimeters. The depressions are sections of spheres made by passing a horizontal plane through the spheres, the segments remaining in the mud

being less than a hemisphere. There are no appreciable raised rims, t surface of the mud being flat from the depressions outward. The edg of the depressions are sharply defined and regular. The surfaces of t pits are smooth to the eye, but are irregular in microscopic detail (fi ure 5).

In the writer's experiments, bubbles were formed by having a spray (water fall on an artificial upland, the falling waters making the bubble which then floated into a tank in which the water was kept at a shallo

FIGURE 6.—*Impressions made by floating Bubbles*

In the lower left-hand corner of the photograph are impressions made by exploding bubbles in very liquid mud.

level over clay and fine sand. After many bubbles had become anchor the mud was permitted to dry. Wherever bubbles remained until t mud had settled to an extent sufficient not to flow, impressions remaine Bubbles were also formed by mixing water and mud in a pan, the agit tion creating the bubbles, which were anchored by the suspended mı settling on them. It was found that impressions of this kind were form whenever shallow muddy waters had bubbles formed in them. They mı be formed in large numbers on every tidal mud flat and on every riv

floodplain. The photograph of this type of impression also shows impressions of the type described under the next heading.

An interesting result arising from the experimental work on this and the succeeding type of bubbles is shown in figure 6. In these experiments the preliminary work was done and the material was left to settle and clear. In nearly every case trails were observed on the surface of the mud. Search was made for worms, but none could be found. It was subsequently observed by one of the students in the course in sedimentation, Mr. C. G. Carlson, that the trails were made either by floating bubbles or small particles of floating matter. Wherever these touched bottom, a trail was made in the soft mud, and many of the bubbles before their stranding did quite a bit of wandering. It thus developed that "worm trails" may also be developed by bubbles.

Impressions made by Bubbles developed from the expelled Air of overflowed Surfaces

Impressions formed by bubbles arising from air expelled from dry surfaces flooded by sediment-loaded waters are like those of type 4, where the bubbles remain attached to the mud until it has solidified sufficiently so as not to flow. It has been found that when dry earth is flooded air is expelled in large quantities and impressions arising from bubbles of this origin must be formed on all tidal flats at the times of flooding and on all floodplains. The writer has observed impressions of either type 4 or 5 in many parts of the country and for a long while considered them to have been made by rain.

Impressions made by Bubbles floating in Waters which are gently Rising and Falling

Bubbles floating in very shallow waters, which are gently rising and falling a few millimeters because of wave activity, produce pits in finely divided muds. If the bubbles be changing position while they are thus rising and falling, rows of pits will be developed. These pits are approximately the same dimensions as the bubbles which produced them. They differ from the pits made by bubbles of the origin already described, in that the surfaces of the impressions are not smooth, but irregular, the margins are not sharp, and the depressions are shallow. Furthermore, the motion of the water tends to make them shallower and ultimately to obliterate them.

Impressions made by Bubbles produced from Decay of organic Matter

Bubble impressions formed on the bottom of water bodies by gases expelled from the mud, the gases arising from the decay of organic matter contained therein, will be similar to the impressions made by the bubbles becoming anchored to the bottom in those cases where the bubbles remain attached to the mud surfaces until the mud ceases to flow. If, however, the bubbles burst from the mud explosively, the effect on its surface will be that of a small explosion, and a conical depression with a slightly ele-

Figure 7.—*Impressions made by Bubbles rising through Mud and bursting on the Surface*

vated margin may be formed (figure 7). If the bursting of the bubbles take place while the mud is in a fluid form, no sooner is the depression formed than the mud flows into it, so that it loses any elevation about the margin it may have had and becomes shallower and wider. It appears that, once a bubble has formed a path, others produced near the same point will follow the same course, and as the mud settles to the degree of not flowing, there results a nearly vertical hole which may extend as far down as the source of the bubbles. In holes so made by the writer, they have been found to be open to a depth of two inches from the surface of the mud. Holes of this character resemble those made by worms, and it is possible that some of the vertical worm-holes which have been reported

from different portions of the geologic column are of this origin. Impressions of this origin should be associated with sediments rich in organic matter.

In the writer's experimental work, impressions of this kind were made by using lake muds and placing yeast for making bread beneath the mud, and also by submerging caked dry clay beneath in the muds.

Pit and mound Structures developed in rapidly precipitated Mud

The pit and mound structures in Kindle's experiments were formed in clay precipitated in salt water, the settling of the clay being accompanied by small upward currents in parts of the mud. The experiments were made in quart milk bottles of the constricted neck type, and the upward currents made their appearance at the beginning of the constriction. In vessels with no constriction, similar structures were not formed. The pit and mound structures were developed on the surface of the settling clay at the places where the upward currents discharged, and consisted of small mounds of 3 to 10 millimeters in diameter, each with a small crater-like depression on its summit, the depression having a diameter the size of a pin-head or smaller. Similar structures were not observed to develop in sediment deposited in fresh water, and Kindle ascribed them to the rapid settling of the mud induced by the salt in the water. In the writer's experiments, mud and water, both fresh and salt, were thoroughly mixed, so as to make a thick soupy-like fluid. This was then poured into tanks and permitted to settle. Over the surface many small currents of water were observed to be rising from the mud, and these developed small mounds. The water appeared to have been squeezed from the settling of the mud. The small currents could be observed with the eye, but not well. Under the microscope they were seen to be bringing up small quantities of suspended material and piling this about the margins of the small openings. It was also found that the shape of the vessel is not a controlling factor. No such phenomena were observed in muds that were permitted to settle gradually. In the present state of knowledge, it thus appears that structures of this type develop wherever large quantities of sediments are precipitated, irrespective of whether the waters are fresh or salt; but, as this is more likely to occur in salt than in fresh water, it should follow that these structures should be more characteristic of deposits of the former than the latter.

Impressions made by organisms consist of pits at the openings made by burrowing animals, the pits made by floating plants touching the bottom

as they rise and fall with the waves, and Doctor Woodworth[6] has called the writer's attention to the fact that certain jellyfish may make pits under the same conditions. Some of these structures of organic origin might be mistaken for impressions made by other agents. These structures are not described in this paper, as their manifold varieties constitute a large task, requiring observations extending over a long period of time.

General Summary

Excepting the pit and mound structures and those made by organisms, the impressions described on previous pages are of two general types: impressions made by falling substances and impressions made by bubbles. The former can be developed only on exposed surfaces of mud or sand, and, as those made on the latter are apt to disappear when the sand dries out, it follows that the preservation of these impressions should generally occur in deposits that contain sufficient mud to hold the material together after drying has occurred. The bubble impressions can be made on surfaces that are covered with water from extreme shallowness to great depths. Types 5, 6, and 7 are favored by shallow water; type 8 may occur in waters of any depth. Types 5, 6, and 7 have nearly the same significance as impressions made by drip, rain, and hail, but they can not be told from some of these formed in the manner described for type 8. The bubbles developed in muds rich in organic matter, which explode on reaching the surface of the mud, make shallow depressions which are much like those made by rain-drop, drip, hail, and spray and splash, but such impressions are ape to be continued downward by tubes. Since impressions of this origin should occur most generally in deposits rich in organic matter, while the other types of impressions may be associated with any type of mud, this fact may enable one to distinguish sediments which were subject to exposure from those made under water. If impressions occur in sediments poor in organic matter and have considerable distribution, it is probable that they were formed in shallow waters whose bottoms were at times exposed. If the impressions of such occurrence are margined by an elevated rim, they were probably made by hail, rain, drip, spray, or splash. If the impressions are in deposits which are rich in organic matter, one should be careful in deciding as to the origin of the deposits. The raised rim of the rain-drop, hail, drip, spray, and splash impressions may not always be preserved, but as there are always many of such impressions, careful search may prove the presence of the marginal elevations.

[6] Personal communication, March 21, 1921.

From what has been stated on foregoing pages, the writer is of the opinion that impressions which have been ascribed to falling rain are of such origin in only a small percentage of cases. If this view be correct, it follows that conclusions based on the occurrence of rain impressions can not be considered valid unless data are given proving that the impressions were really so made. As a criterion for the determination of deposits formed under conditions of occasional exposure to the atmosphere, the occurrence of small depressions is valuable, but must be used with great care, and the determination should always be made that the depressions are margined by elevated rims and are not continued downward as tubes.

Wherever bubbles or, for that matter, any floating objects come in contact with soft muds, trails are made which resemble worm trails and may be mistaken for such. As a general fact, the trails are very shallow. Bubbles rising through mud of favorable consistency form vertical tubes which may be mistaken for worm tubes.

Impressions of the types described are made on the upper surfaces of strata and there occur as depressions. Their obverse is on the under side of the overlying strata, where they occur as wart-like mounds. It hence follows that where impressions made by rain, bubbles, etcetera, are present, one is enabled to tell which is the top or younger side of a section, and this may give the key to the unraveling of a problem in complicated structure.

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SYNGENETIC ORIGIN OF CONCRETIONS IN SHALE[1]

BY W. A. TARR

(Read before the Society December 28, 1920)

CONTENTS

INTRODUCTION

Concretions may be divided into two classes as to origin: (1) syngenetic, or those which were deposited or formed at the same time as the inclosing beds, and (2) epigenetic, or those which have been formed subsequent to the deposition of the surrounding beds. The syngenetic concretions would be older than the beds under them and younger (for the most part, at least) than the beds over them, and the epigenetic concretions would be younger than any of the surrounding beds, because they are due to growth by the addition of material *from the surrounding rocks.*

[1] Manuscript received by the Secretary of the Society April 16, 1921.

This classification differs from that of Todd,[2] but includes his four classes in two, grouping them on a basis of their age relative to the surrounding rocks rather than on the movement of the materials in the concretions proper. Grabau[3] follows Todd in his classification.

There is evidence to support each class, but in the main the published views favor an epigenetic origin. Within the last two years the writer has encountered evidence which appears to strongly favor a syngenetic origin for concretions in shales. This evidence will be presented below after a brief statement of prevalent views. It should be noted that this paper deals mainly with the syngenetic origin of concretions rather than with the origin of the concretionary form itself.

Prevalent Views as to Origin

The recent literature bearing on the origin of concretions, though not abundant, indicates that the prevalent view favors an epigenetic origin. Pirsson and Schuchert[4] state:

"While some are very pure, they [the concretions] often contain large amounts of rock material, and in some cases the planes of stratification can be seen passing through them. Their origin appears to be due to material in the rock having gone into solution, and then for some reason having been steadily redeposited around certain centers as neuclei, thus building up the concretions."

Chamberlin and Salisbury[5] make the two following statements:

"The concretion may be made up almost wholly of concentrated matter, in which case the matter originally in the place of the concretion has been crowded aside; or it may involve much of the material of the embedding rock. . . . Concretions of the sort indicated above often develop after the inclosing sedimentary rock was deposited. This is shown, among other things, by the fact that numerous planes of lamination may sometimes be traced through the concretions. Concretions also form in water during the deposition of sedimentary rock."

They refer in the last sentence to oolites and pisolites.

Cleland[6] states that concretions may be of both syngenetic and epigenetic origin. He states:

"They are often formed before the rock containing them is hardened [indurated], as is shown by the fact that (1) they are often cut by joints, and (2)

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[2] J. E. Todd: Concretions and their geological effects. Bull. Geol. Soc. Am., vol. 14. 1903, pp. 353-368.

[3] A. W. Grabau: Principles of stratigraphy. 1913. pp. 718 and 763.

[4] L. V. Pirsson and Charles Schuchert: Text-book of geology. 1915. p. 273.

[5] T. C. Chamberlin and R. D. Salisbury: Geology, vol. 1, pp. 492 and 496.

[6] H. F. Cleland: Geology, physical and historical. 1916, p. 77.

when they contain fossils these remains are seldom flattened by the pressure of the overlying rocks as are those in the surrounding shale. Although many of the concretions which occur in sedimentary rocks were formed while they were in an unconsolidated state and before they were deeply buried, there is no doubt that some were formed after the sediments had been consolidated into rock."

J. H. Gardner[7] holds that certain concretions which are largely argillaceous "are contemporaneous with the strata in which they are contained." These argillaceous concretions may be flattened clay balls, according to his view.

R. A. Daly[8] has described the concretions in the shale at Kettle Point, Lambton County, Ontario. He states that these concretions occur in well laminated bituminous shales and are pure calcium carbonate. They are spherical, have a radial structure, and have pushed the bedding planes apart. Daly states that the concretions were formed in place within the shale, but that they antedate the period of joint development and final consolidation of the surrounding rock.

It is not unlikely that concretions have been formed shortly after the first deposition of the sediments, as Daly suggests was the case at Kettle Point, but it is not improbable that the concretions at this locality are syngenetic. Their occurrence along a definite plane, their radial structure and large size, which implies an abundance of material, all favor this view.

In connection with the last statement, that concretions might be formed in sediments shortly after their first deposition, the possible effect of Liesegang's rhythmic precipitation should be mentioned. S. C. Bradford,[9] in conducting some experimental work on the Liesegang phenomenon, observed certain concretionary growths in various zones in his agar gel. He pointed out that this might explain the concretionary structure of certain limestones and marls. Such an origin would, of course, be epigenetic, as defined in this paper. There would seem to be little to support the view that a calcareous mud is capable of supporting the movement of materials, as is demanded by the Liesegang phenomenon and is so beautifully shown by gels. Experimental studies along these lines and dealing with the materials of rocks are to be desired.

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[7] J. H. Gardner: The physical origin of certain concretions. Jour. Geol., vol. 16, 1908, p. 452.

[8] R. A. Daly: The calcareous concretions of Kettle Point, Lambton County, Ontario. Jour. Geol., vol. 8, 1900, p. 135.

[9] S. C. Bradford: The Liesegang phenomenon and concretionary structure in rocks. Nature, vol. 97, 1916, pp. 80-81.

Other citations are possible,[10] but these are sufficient to indicate the line of thought as expressed in recent text-books and articles.

There is abundant evidence that concretions in sandstones are epigenetic, and very probably the same is true of concretions in any permeable formation. Shale, in contrast to sandstone, is an impermeable rock, as is proven by its being the confining formation for underground waters and for oil and gas. Concretions in shale, therefore, present a more difficult problem. As indicated by the above quotations, where the bedding planes of the inclosing rock pass directly through the concretion, cementation of the rock material in place is evident. The discoid form so common in concretions has been interpreted to confirm the same method of origin, deposition following the bedding planes. This form, however, may be due to flattening by pressure, as the writer has shown to be the case in chert concretions in the Burlington limestone.[11] Strong evidence of an epigenetic origin would be the sharp crumpling of the beds at the sides of the concretion as it expanded through lateral growth. Singularly enough, such crumpling is absent from all concretions in shale which the writer has been able to examine.

Field Studies of Concretions in Shale

CONCRETIONS IN THE PENNSYLVANIAN (CHEROKEE) SHALES IN MISSOURI

Concretions occur in a three-foot bed of black shale in the Pennsylvanian shales in Boone County, Missouri. The concretions range in diameter from one-quarter of an inch to twelve inches. They are composed of kaolin and silica and are only slightly calcareous. The larger concretions contain well preserved fossils in the outer part or on the upper surface. Usually the concretions are elliptical in cross-section and circular to elliptical in plan. Irregular forms also occur and many are rudely symmetrical.

The relationship of the concretions to their surrounding beds is of especial interest. The concretion rests in a shallow cup and the remaining beds arch over it. No stratification lines pass through the concretions. Since the greater thickness of beds arches over the concretion, the bend at the sides would be very abrupt, were it not for the fact that small lenticular beds lie in this pocket next to the concretion. These rapidly pinch out away from the concretion and are apparently due to material

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[10] The writer's attention has been called to an excellent article by J. M. Arms Sheldon, "Concretions from Champlain clays of the Connecticut Valley," Boston, 1900, which has a very fine bibliography, but he has been unable to see the original.

[11] W. A. Tarr: Origin of the chert in the Burlington limestone. Am. Jour. Sci., vol. xliv, 1917, p. 438.

slipping off the steep sides of the concretion and accumulating around it (see figure 1). As burial proceeded, the normal bedding planes passed over the concretions and eventually all evidence of the concretion died out.

A feature of considerable import noticed on these concretions was their marked slickensides. These were on both the under and upper sides, but were far less perfectly developed below. In the entire absence of evidence

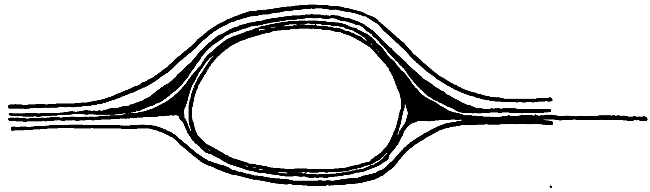

FIGURE 1.—*Sketch of Concretion in Pennsylvanian Shale in Boone County, Missouri*
Shows lenses of clay between the bedding planes.

of lateral growth, such as crumpling of the beds, which would be necessary in these beds, because the concretion is not due to local cementation, as shown by the stratification planes passing over and not through them, it must be concluded that the slickensides are due to upward growth subsequent to deposition, or that the beds slipped down around the concretion during consolidation.

CONCRETIONS IN THE CRETACEOUS (GRANEROS) SHALES IN SOUTH DAKOTA AND WYOMING

The lower part of the Graneros shale (Cretaceous) in the northern Black Hills contains many concretions. Some of the best of these are in

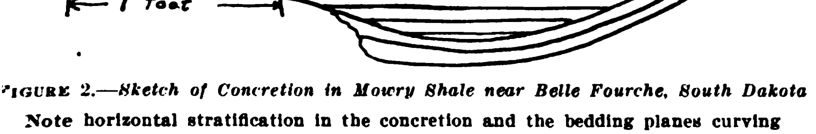

FIGURE 2.—*Sketch of Concretion in Mowry Shale near Belle Fourche, South Dakota*
Note horizontal stratification in the concretion and the bedding planes curving around it.

e Mowry shale member. These concretions attain a length of 6 or 7 t and a thickness of 15 to 18 inches. They are circular, elliptical, and egular in plan and distinctly lenticular in cross-section, becoming

rather thin near the edges. The concretions are composed of shale and silica and are very hard. They lie along one bedding plane, but there is no regularity in the lateral spacing or in their size. Occasionally they show a very fine septarian development. A band of cone-in-cone frequently occurs along the top of these concretions. This band in some instances was three inches thick.

The bedding planes in those studied *curve under* and *over the concretions.* The concretions themselves show *parallel lines of stratification, but they end with the concretion* and are not continuous or connected with those of the surrounding beds (see figure 2). There is apparently but one conclusion to draw from such occurrence, and that is that the concretion antedates the overlying beds and is subsequent to the beds it rests on, since its own banding is independent of both.

CONCRETIONS IN THE CRETACEOUS (CARLISLE) SHALES IN SOUTH DAKOTA AND WYOMING

Concretions are very abundant in the Carlisle shale in the northern Black Hills region. The formation is a dark gray to black shale about 600 feet thick. The concretions are especially well developed in the lower and upper parts. Near the base are several lines of flat, elliptical concretions, around which the bedding planes pass. A short distance above these are some very large, more or less spherical concretions, which attain a diameter of several feet. They are composed of sandy limestone and are horizontally banded like the adjacent shales. Septarian cracks give a radial and concentric appearance to them. Horizontal bands of cone-in-cone, 2½ inches wide, run entirely across some of them. None of these concretions were seen entirely surrounded by the shale. The most notable point is their distribution along a definite horizon.

The upper portion of the Carlisle shale is full of concretions, which occur consistently along one bedding plane, the successive lines of concretions occurring at intervals of from 15 to 30 feet and averaging about 20 feet apart. These concretions range up to 18 inches in thickness and may be 10 feet long. This length is due mainly to adjacent concretions coalescing. They are composed of a fine-grained gray limestone or calcite and all show septarian cracks which are filled with a yellow to deep brown calcite.

There is an immense number of these concretions in this portion of the shale, and although they are always along definite planes they are irregularly spaced on these planes. The significance of their occurrence and distribution will be noted under origin.

CONCRETIONS IN THE CRETACEOUS (PIERRE) SHALES IN SOUTH DAKOTA AND WYOMING

Concretions occur in the Pierre shale in the same region mentioned above for the Graneros and Carlisle. Although not so common, when they do occur it is always along one bedding plane. This distribution along one plane is well shown in an illustration in an article on the concretions of the Pierre shale by Carrie A. Barbour.[12] They are extremely ferruginous, calcareous concretions and are always found in dark shales.

CONCRETIONS IN THE CRETACEOUS (CLAGGETT) SHALES IN HILL COUNTY, MONTANA, AND SOUTHERN SASKATCHEWAN, CANADA

Scattered calcareous concretions occur in the black Claggett shales in northern Montana and southern Saskatchewan. Although they are not numerous, they are found along one plane and are usually elliptical and small, less than a foot in diameter. Nothing could be determined as to their relationship to the bedding planes, beyond the fact that different lines of concretions followed one plane.

Origin of the Concretions

The significant points noted above are (1) concretions in shales are dominantly along planes which are variously spaced vertically; (2) the bedding planes curve around the concretions in every case where this relationship was determinable; (3) in at least one instance the concretion contained bedding planes not continuous with the surrounding planes which curved around the concretion; and (4) they may show slickensides.

These points are believed to indicate a syngenetic origin for the concretions for the following reasons: The recurrence of planes of concretions, without isolated concretions between, points to a varying source of material in the water in which the sediments were being deposited. When the concretions are mainly calcium carbonate, as they are in the Carlisle, Pierre, and Claggett shales, deposition occurred when the lime salts in the water reached the saturation point. Since the concretions are distributed along each plane, it is readily seen that had this amount of calcium carbonate been greater, a thin bed of limestone would have resulted. Geologists have long accepted without question the fact that alternating beds of shale and limestone are due to differences in the rate of supply of calcium carbonate and of its reaching the saturation point. Why the calcium carbonate should take the concretionary form instead

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[12] Carrie A. Barbour: Observations on the concretions of the Pierre Shale. Proc. Neb. Acad. Sci., vol. 7, 1897, pp. 36-38.

of being uniformly distributed must be determined by future studies. It is not improbable that an excessively rapid precipitation would mean a bed of limestone and a slower rate would result in the material assuming a concretionary form. It is apparent that the successive recurrence of planes of calcareous concretions and the recurrence of successive beds of limestone have so much in common that the above view as to their syngenetic origin of the concretions in shales is just as probable as the view of the syngenetic origin of beds of limestone when both occur interbedded with shales.

In all the instances where the relationship of the concretion to the surrounding beds could be studied it was found that the lines of stratification went around the concretion. When the major part of these lines go over the concretion it suggests a syngenetic origin with subsequent burial. Growth subsequent to deposition would produce an arching of the beds, unless the concretion is the result of cementation. If the concretion is spherical, as the majority of them are, this arching of the beds would leave a y-shaped opening entirely surrounding the form. This opening should be filled if laterally moving solutions were bringing in material and the concretion would lose its spherical form. This type is rare. In the concretions from the Pennsylvanian in Missouri this space was filled by thin lenses of shale, the material having accumulated around them after they had attained their present size (see figure 1).

When the lines of stratification curve around the concretion and when the concretion shows lines of stratification which are independent of those around it, the evidence appears convincingly favorable to a syngenetic origin. The stratification lines in the concretion developed as the material which formed it (largely silica and kaolin in the Mowry shale member in the northern Black Hills) accumulated. With a fresh influx of mud, further growth was cut off and the concretion was buried.

The slickensides on some concretions are open to more than one interpretation. If considered alone, they could be due to the beds being pushed up by growth or to the beds slipping down around the concretion. When studied in connection with the arching of the beds and the lack of lines of stratification passing through the concretion, they are taken to mean that the beds during consolidation settled down around the concretion. Further, when the concretions are of the same material as the shale, largely kaolin and silica, and are not due to cementation, their volume (see below) favors a syngenetic origin, as it is impossible that they could have displaced so much rock by pushing it aside.

Correlative Evidence of syngenetic Origin

FOSSILIFEROUS CONCRETIONS

Last year the writer read a short paper to the Geologic Section of the American Association for the Advancement of Science on the syngenetic origin of the concretions in the Pennsylvanian shales in Missouri, and in the short discussion which followed the point was made by David White and others that the beautifully preserved fossils, both plant and animal, so frequently found in concretions were certainly favorable to their syngenetic origin.

The concretions which are so abundant in the sandy shales along Mazon Creek, Grundy County, Illinois, furnish excellent examples of the wonderful preservation of organic remains in concretions. The fossiliferous concretions are especially abundant in a nearly pure clay shale. Leo Lesquereux[13] makes the following statement regarding them:

"They appear to have been formed by superposition of concentric layers of slowly deposited carbonate of iron or ferruginous clay around central nuclei, which are most commonly parts of plants, bones of fishes, or the remains of insects and crustacea. Their size and form vary according to that of the body around which the deposit has been made."

He states further:

"It is not clear whether the flattening of some of the specimens is the result of compression."

Cylindrical stems preserve their original shape. Discussing their origin, this interesting statement, especially in the light of Harder's valuable studies of iron bacteria, is made:

. . . "the nodules of Mazon Creek rather seem to be the work of infusoria or Bacillaria concentrating molecules of iron around some centers, as it now happens in the formation of bog iron ore." . . .

Lesquereux makes the following remarks about the perfect preservation of even the minutest detail of the plants:

"The pinnæ or leaflets of ferns are always found in them in a flattened position, their axis or rachis extending through the center of the elongated nodule, with the divisions on both sides; the surface of the pinnules, slightly swollen, as when in their living state, is marked by recognizable hairs or fruit dots, with distinct veins and veinlets, and their appendages, like the scales, are seen in the various modifications which they present in living specimens. . . . The smaller organs of plants appear, therefore, in a better state of preserva-

[13] Leo Lesquereux: Geological Survey of Illinois, vol. iv, pp. 481-483.

tion than in the shales. With small animals like crustaceans, scorpions, insects of a fleshy and very delicate texture, the preservation of form is still more remarkable. They are found entombed in the middle of nodules, just as if they were in life, or as if they had been transformed into stone while still living. The fruits or nutlets are not flattened."

Remarking further in regard to their preservation, he makes this comment:

"Yet as the animals and plants of soft texture . . . have not yet been found in the shale of our American Coal Measures, it is evident that these remains have been generally destroyed by maceration, and only escaped total destruction by their entombment in these nodules."

Certainly in such instances as these there can be but little doubt that the fossil form was so completely inclosed before burial that the presence of the superincumbent beds did not crush in the slightest degree the organic forms. The iron carbonate of which the concretions are largely composed was evidently deposited around the organism before further sedimentation occurred.

No doubt instances of equally well preserved organic remains within concretions have come to the notice of many paleontologists and geologists.

PHYSICAL FACTORS

Shales are recognized as impermeable rocks. They form the cap for most oil and gas pools, as well as the overlying rock in water-bearing sands. The movement of water through such rocks is at a minimum. Movement does not take place even along bedding planes, and without movement of water the material in the concretions could not be aggregated.

When the concretions are largely silica and clay and are covered with numerous calcareous fossils which are splendidly preserved, the difficulties of explaining the source of the materials or accounting for an adequate transportation agent, and explaining why the calcareous fossils should be aggregated at that particular point and not be replaced by the incoming material, make an epigenetic origin appear impossible. The fossils are embedded in the material of the concretions in the Pennsylvanian of Missouri. They have every appearance of having fallen into a soft, jelly-like material and having been there protected from further alteration or deformation. If the silica in the concretions had been in a colloidal state, as the writer has shown to be the case for the chert in the Burlington limestone, the numerous fossils in association with the concretions is more readily understood.

The task of aggregating through ground-water action the enormous volume of calcareous material involved in the limestone concretions in the Carlisle shale, for instance, where they are very numerous along planes at an average interval of 20 feet, would have been a Herculean task, even for ground-water. Had the calcareous material been distributed originally along one plane, then the concretions should be elliptical in cross-section, as the major part of the deposition would be at the sides. If the calcareous material was originally distributed throughout the shale, the concretions should be irregularly distributed, for the uniformity of the shale would not favor segregation by ground-water along certain planes. This distribution along one plane and of successive planes of concretions, if one accepts a syngenetic origin of them, would be dependent on the laws controlling an alternating series of shales and limestones, or that controlling the deposition of colloidal silica, as chert.

The volume of some of the large concretions in shales should be considered. The materials composing the shale may be regarded as insoluble, as far as this problem is concerned. A volume of shale equal to that of the concretions must be displaced. Taking a large concretion, such as those in the lower part of the Carlisle, where some concretions are 5 to 6 feet in diameter, the volume ranges from 65 to 215 cubic feet. Compression due to expansion by growth can hardly account for the development of this space, and neither would many of us accept the view that this volume of shale had been removed in solution. A syngenetic origin does not encounter this objection.

SUMMARY

Most concretions which occur in shales are probably of syngenetic origin. Concretions found in the Pennsylvanian in Missouri and Illinois and in the Cretaceous in South Dakota, Wyoming, Montana, and southern Saskatchewan present evidence which strongly supports this view.

This evidence is as follows:

(1) The concretions are arranged along one plane.

(2) There are frequently successive planes of concretions in a formation.

(3) Their volume is too large to be accounted for by an epigenetic growth, without cementation of previously existing materials.

(4) The inclosing beds arch over the concretions.

(5) The sides are slickensided by a slipping down of the beds around the concretion.

(6) In a few instances it was determined that the stratification planes in the concretions were distinct from those in the inclosing beds.

(7) The occurrence of concretions dominantly along one bedding plane should be accepted as indicating a syngenetic origin for such concretions as readily as we accept a syngenetic origin for beds of limestone under similar conditions.

(8) The perfect preservation of fossils within the concretions points to its development previous to burial.

(9) It is difficult to understand how an insoluble material like silica can be aggregated in an impermeable material like shales, or how and why the large amount of calcareous material in the successive lines of concretions, as in the Carlisle formation, should be concentrated along these planes, unless we accept a syngenetic origin for at least a part of the concretions in shales.

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SOME CONCLUSIONS IN REGARD TO THE ORIGIN OF GYPSUM [1]

BY FRANK A. WILDER

(Read before the Society December 29, 1920)

CONTENTS

Prevailing Opinion in regard to Origin of Gypsum

The prevailing opinion seems to be that most of the important gypsum deposits of the world have been formed under "salt-pan" conditions. This opinion is held, even though many persons have pointed out the difficulties which the theory involves.

The classical illustration of the "salt-pan" theory for gypsum deposits is found in certain nearly detached basins at the eastern end of the Caspian Sea and elsewhere. Conditions in these basins, however, in at least one important particular, differ from those that characterize gypsum deposits. Myriads of organisms are drawn into the basin from the Caspian Sea and perish in its denser brine. Gypsum deposits, on the other hand, are generally devoid of fossils. To avoid this difficulty, certain students of the problem have postulated a second, or inner, basin in which the brine reaches the gypsum-depositing stage. According to this conception, the remains of organic life would be deposited in the intermediate basin, together with some of the lime carbonate.

[1] Revised manuscript received by the Secretary of the Society May 2, 1921.

Difficulties of generally accepted Theory

Theories that seek to explain extensive deposits of gypsum as the direct result of the evaporation of brines in natural basins are quite involved. They require the nice adjustment of a number of factors, and at best they fail to wholly explain how thick beds of practically pure mineral can be formed free from lime carbonate and silt and devoid of fossils.

No extensive beds of practically pure gypsum due to the evaporation of sea-water are known to be in process of formation. Gypsiferous beds due to the evaporation of saline waters are forming in a great many localities, but the gypsum is present, either as scattered crystals in mud or as thin streaks with other salts. On the other hand, extensive beds of practically pure gypsum are today being formed by other agencies.

In 1910 F. L. Hess[2] grouped gypsum deposits in four classes. His arrangement of these classes deserves notice:

1. Efflorescent deposits.
2. Periodic lake deposits.
3. Interbedded deposits.
4. Veins.

The text of the bulletin gives the impression that "efflorescent deposits" is purposely placed first. Apparently he arrived at this arrangement and classification because his studies were made in California and included large arid areas where interesting gypsum deposits occur.

R. W. Stone, whose bulletin on "Gypsum deposits of the United States" [3] is just from the press, adopts a similar classification for gypsum deposits derived from solutions. He further adds deposits produced by alteration and deposits produced by disintegration and mechanical reaccumulation.

Although these classifications reduce the emphasis laid on deposits due to direct evaporation of brines, the evidence seems to show that extensive deposits of gypsum of this sort are extremely rare, if, indeed, they exist at all.

The Lime Carbonate Problem

In the first place, the difficulties growing out of the presence of lime carbonate in sea-water are greater than is generally realized. Prof. Julius Stieglitz, in an interesting discussion of the relations of equilibrium be-

[2] F. L. Hess: A reconnaissance of the gypsum deposits of California. U. S. Geol. Survey Bulletin 413, 1910.

[3] Gypsum deposits of the United States. U. S. Geol. Survey Bulletin 697, 1920.

tween carbon dioxide in the atmosphere and the calcium sulphate, calcium carbonate, and calcium bicarbonate of water solutions in contact with it,[4] makes it plain that:

1. If the natural waters of the earth were supposed to contain only lime salts—that is, the sulphate, carbonate, and bicarbonate in equilibrium with the carbon dioxide of the atmosphere—and if the average partial pressure of carbon dioxide in the atmosphere were the same as at present (0.0003 atmosphere), by evaporation the gypsum would be precipitated with contamination of .9 per cent of calcium carbonate. If the carbon dioxide were reduced to 1/10 the amount in the present atmosphere—a condition hardly conceivable—the gypsum would still be precipitated with contamination of calcium carbonate, though the amount would be reduced to .3 per cent. If the carbon dioxide were increased to 10 times the amount in the present atmosphere, the calcium carbonate contamination would increase to 2.85 per cent.

2. The presence of other sulphates which might be found in sea-water would increase the calcium carbonate contamination of the gypsum.

3. An increase of temperature by decreasing the coefficient of absorption of carbon dioxide would possibly be a favorable factor in the formation of pure gypsum by evaporation of sea-water. Such increase in temperature, however, would probably come with an increase in the amount of carbon dioxide in the atmosphere, and, as has been noted, an increase in the carbon dioxide content of the atmosphere means a rapid increase in calcium carbonate contamination of the gypsum.

4. The presence of very large amounts of sodium chloride (about 8 to 25 per cent) would have a tendency to reduce the calcium carbonate contamination.

Stieglitz calls attention to Usiglio's work on mediterranean water, where calcium sulphate began to be deposited when the water reached the density of 1.13, which corresponds to a chloride content of 17 per cent. This concentration, Stieglitz states,[5] was reached in Cameron's experiments for solution 7, from which, going to solution 8, gypsum would be obtained with about .8 per cent of carbonate.

5. "Even if the great mass of an excess of calcium carbonate in a solution were deposited first in some other locality before the point of saturation for gypsum were reached, the requirements for equilibrium would be such as to hold carbonate in solution and to make the question of the place of deposit of the excess of carbonate in the first instance one of no moment."

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[4] The tidal and other problems. Published by the Carnegie Institution of Washington, 1909.

[5] The tidal and other problems. Carnegie Institution of Washington, 1909, p. 262.

As a result of Stieglitz' work, it seems necessary to draw the conclusion that it is very unlikely that gypsum that contains less than one-half of 1 per cent of calcium carbonate was formed under salt-pan conditions.

Inasmuch as there are many published analyses of gypsum which contain less than one-half of 1 per cent of calcium carbonate, it seems necessary to take such deposits out of the salt-pan class or else to suspect that the analyses were not made with sufficient care with reference to calcium carbonate. In some cases there is ground for doubting the accuracy of the analyses. Recent analyses of the Fort Dodge, Iowa, gypsum, for instance, show sufficient calcium carbonate to permit the supposition that they were deposited from sea-water, though earlier analyses had shown no carbonate. Analyses of a great many interesting and important deposits remain, however, that record no lime carbonate, and unquestionably some of these analyses were carefully made and correctly represent the composition of the deposit. This list of carbonate-free deposits contains those in—

Montana:
- Douglas,
- Empire Mountain.

California:
- Amboy,
- Palmdale.

Florida:
- Penasoffkee.

Iowa:
- Centerville.

Kansas:
- Kling.

Montana:
- Great Falls,
- Armington,
- Boulder.

New Mexico:
- White Sands of Alamogordo.

Oklahoma:
- Cement,
- Medicine Lodge,
- Southard.

Utah:
- Lovan,
- Nephi.

Wyoming:
- Red Buttes.

Certain portions of the gypsum in Virginia and at Medicine Lodge, Kansas, contain lime and magnesium carbonate, while other portions seem to contain no carbonate.

From the study of published descriptions of gypsum beds, it is apparent that in most instances these beds rest directly on shale or sandstone. This seems rather remarkable, in view of the amount of calcium carbonate in ocean water and in the waters of rivers in arid regions. Some of this carbonate may have been segregated near the entrance of the receiving basin. Agencies that result in such segregation have been pointed out by numerous observers. Nevertheless, it is not clear what becomes of much of the carbonate, over and above that which Stieglitz has shown must come down with the gypsum.

E. B. Branson[6] states that—

"A 40-foot bed of gypsum, resulting from the evaporation of 57,000 feet of normal sea-water, should have nearly 3 feet of limestone below it, if the evaporation all took place in a restricted basin; but if the waters were widespread in the beginning, about half of the limestone might be deposited over the wider area, as more than half of the $CaCO_3$ precipitates when the volume of sea-water is reduced about 50 per cent, and the limestone below the gypsum might be less than 2 feet in thickness. The writer has not seen limestone immediately below the gypsum at any place in the Red Beds."

The localities listed above as containing important gypsum deposits free from lime were selected because it was felt that the analyses were carefully made, and that the analysis represented the average of the mineral body and not merely a selected sample. For this reason particular weight was given to analyses made by the chemists in the employ of manufacturers of gypsum products, for it was felt that they had a special reason in securing an "average analysis." In the future, when gypsum is analyzed, let us hope that the presence or absence of even small quantities of lime carbonate may be fully demonstrated.

Nature of present-day Deposits

CONCENTRATION OF DISSEMINATED GYPSUM

More attention should be directed to the gypsite beds of the western United States, to the wonderful "white sands" of Alamogordo, New Mexico, and to similar gypsum deposits in Utah and Australia. These are generally recognized as originally efflorescent deposits, formed on the surface by the evaporation of water that has seeped through gypsiferous strata, the gypsum grains so formed being later piled up by the winds. Salt that may have come to the surface with the gypsum readily leaches out. The statement has been made by advocates of the salt-pan theory that such wind-blown deposits can not be pure; yet the gypsum dunes of New Mexico, Utah, and Australia are remarkably pure. Gypsum deposits showing cross-bedding, like those reported in Oklahoma by L. C. Snider,[7] may represent efflorescent wind-blown material.

According to G. W. Stose,[8] the gypsum deposits of Virginia were probably derived from calcareous-argillaceous sediments which originally contained disseminated gypsum. This gypsum, he believes, was concentrated by underground waters which circulated along the fault between the Carboniferous and Cambrian rocks. While I am not prepared to wholly

[6] Bull. Geol. Soc. Am., vol. 26, no. 2, p. 235.
[7] Mineral Industry, vol. xxiv, p. 371.
[8] U. S. Geol. Survey Bulletin 530, 1913, pp. 232-255.

indorse this view, the Virginia gypsum deposits as now found are certainly not of salt-pan origin.

R. W. Stone[9] believes that the gypsum of Florida has been deposited by springs, and the evidence seems to point definitely to this conclusion. The tremendous masses of gypsum found in the "domes" in Louisiana and Texas are regarded by G. D. Harris and some others as the work of upward-moving waters which carried gypsum in solution.

ALTERATION OF CARBONATE

Before 1877, when Ochsenius published the result of his observations in connection with sea-water, gypsum was generally regarded as an alteration product derived from limestone. Sulphurous waters are abundant and widespread and their ability to change limestone into hydrated lime sulphate is admitted without question. Numerous illustrations may be cited. A striking case at Spatsum, British Columbia, is described by L. H. Cole.[10] Gypsum-bearing rocks occur on the hills forming the west bank of the Thompson River. The rocks of the district are schists, graywackes, and some limestone. Cole says:

> "The surface material consists of a badly disintegrated mass of mica schists, limestones, and shales, with frequent nodular lumps of white gypsum of varying size. After passing through this altered material, which has been lightly recemented, the tunnel cuts through a band of very pure, massive white gypsum, which proved by analysis to be almost a theoretically pure gypsum. This band, however, was only 5 feet wide, with a very light gray or white highly altered hydromica schist, together with some altered limestone, for the hanging wall and for the rest of the length of the tunnel."

O. M. Knode, of the United States Gypsum Company, visited this spot and found a tunnel 40 feet long driven into a bed of crystalline limestone. Sulphurous water originating at a point higher up was seeping through this body of limestone. The whole face of the tunnel was moist and slimy from a deposit of gypsum and sulphur. Analyses of the rock along the sides of the tunnel gave from 12 to 100 per cent of gypsum. Knode's conclusion was that the entire limestone ledge was being altered to gypsum.

There seems to be a frequent association of gypsum with hydrocarbons. The oil domes of the Gulf coast have attracted a good deal of attention, and the fact that great masses of gypsum and salt enter into their structure is well known. F. L. Hess, in his report on the gypsum deposits of

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[9] Gypsum deposits of the United States. U. S. Geol. Survey Bulletin 697, 1920.
[10] Gypsum in Canada, pp. 95, 96.

California, describes an interesting deposit of gypsum with sulphur and hydrocarbons, which is locally known as "The Oil Bubble."[11] The mound, which is 10 to 15 feet high and about 65 feet in diameter, is composed of small crystals of gypsum, most of them less than one-quarter inch in length, mixed with enough clay to permit the mass to be easily kneaded. The mound also contained a small amount of material resembling greatly oxidized asphalt stained slightly with native sulphur. At the time it was visited the mound was wet and sticky and it is said to remain moist throughout the summer. It is reported to give off bubbles of gas; hence the name "bubble," the supposed asphalt suggesting the name "oil."

"The mound is formed by the evaporation of water carrying gypsum in solution, and clay probably being brought to the place by winds. The excessive dryness of the surrounding country makes it seem probable that the water comes from a considerable depth, rising through the Tertiary gypsiferous sandstones."

The gypsum of Virginia is curiously banded with black streaks of hydrocarbon, which entirely disappear when the gypsum is heated to moderately high temperatures. At Stopinshof and Pawasser, in Russia, the gypsum beds are given a dark blue color by their bitumen content.[12]

In the Aspy Bay district in Victoria County, Nova Scotia, the exposure is described as "white and mottled white and gray, compact crystallization showing some little anhydrite, which carries petroleum in small (pea size) cells at the base of the exposures."[13] The gypsum on the Geary property, South Maitland, Hants County, Nova Scotia, is described as containing "considerable anhydrite, and veins of dark carbonaceous and reddish gypsum,"[14] At Cheverie, in Hants County, Nova Scotia, the rock in the Lown Head quarry is described as "carrying petroleum in embedded cells, from which small quantities have been collected during blasting operations."[15] On Avon River, Hants County, Nova Scotia, the gypsum is described as of "a very fine white, compact variety, showing a few streaks of black irregularly distributed through the white. The black was high in carbonate of magnesia and carried some bitumen and iron pyrite."[16] Within the town of Windsor, Nova Scotia, in the old Pellow quarry, from which 500,000 tons of gypsum have been taken, anhydrite

[11] U. S. Geol. Survey Bulletin 413, p. 15.
[12] Dammer u. Tietze: Die Nutzbaren Mineralein, II, p. 68.
[13] Cole: Gypsum in Canada. Canadian Dept. of Mines, p. 189.
[14] Cole: Gypsum in Canada. Canadian Dept. of Mines, p. 214.
[15] Cole: Gypsum in Canada. Canadian Dept. of Mines, p. 218.
[16] Cole: Gypsum in Canada. Canadian Dept. of Mines, p. 222.

here occurs "in lenticular masses from 2 to 10 feet in the center and from 50 to 75 feet long, embedded in the gypsum. Crude petroleum has also been reported as occurring in large cells in nodules of gypsum found in the clay which forms a covering for the deposit.[17]

In Persia and the Near East gypsum is often associated with oil seeps.[18] On the north of the road from Mosul to Bagdad are occurrences where oil seeps from gypsum beds, running out over the road. Oil springs exist in the vicinity of Kifri, about 150 kilometers northwest of Bagdad, where beds of gypsum yield quantities of salt, sulphur, and petroleum. On the Euphrates, in the vicinity of Hit, the natives, with crude working methods, secure about 2,500 tons of asphaltic oil a year from a series of gypsum beds in layers up to two meters thick, intercalated with sandy clays. In western Persia, about 150 miles west of Shustas, seepages yield small amounts of oil for native use. The source is a bed of light yellow loam rich in sulphur and gypsum. According to Harris,[19] the anhydrite in the Douglashall mine at Stassfurt is often bituminous.

Naphtha occurs with the gypsum and salt in the province of Archangel.[20]

The association of gypsum with oil and bituminous shales may be the result of the action of sulphur, which is usually associated with hydrocarbons, on marl or limestone. It may, on the other hand, merely indicate that the same seepage conditions that bring the oil to the surface have been instrumental in concentrating and depositing gypsum.

ALTERATION OF ANHYDRITE

J. A. Udden[21] believes that certain extensive beds of anhydrite in Texas have been formed in connection with the dolomitization of the limestone, as the result of a reaction between magnesium sulphate in the circulating solutions and the calcium carbonate in the original sediment.

Careful observation and study should be directed to the relationships between gypsum and anhydrite. The belief seems to be growing that anhydrite is very often the original mineral from which gypsum has been derived by hydration.

A. F. Rogers[22] states that "from all the most reliable evidence, it

[17] Cole: Gypsum in Canada. Canadian Dept. of Mines, p. 223.

[18] Edmund M. Speiker's review of "Die Turkisch-Persischen Erdölvorkommen," by Schweer, published in Eng. and Min. Jour., August 14, 1920, by permission of Director of U. S. Geol. Survey.

[19] Geol. Survey of Louisiana, Bulletin 7, p. 146.

[20] Fuchs and De Launay: Traite des Gites Mineraux.

[21] The deep boring at Spurr. Bull. Univ. of Texas 363, p. 67.

[22] School of Mines Quarterly, Columbia Univ., vol. xxxvi, no. 2, January, 1915, p. 141.

seems that many, if not most, of the gypsum beds have been formed by the hydration of sedimentary anhydrite." While this statement may be broad, many gypsum deposits have evidently been derived from anhydrite. This is probably true of Virginia gypsum and of the important Nova Scotia deposits about Windsor. In the light of the latest drilling in New York, Newland[28] is inclined to the opinion that the more important deposits of gypsum in that State were originally anhydrite.

Briefly reviewing the statements that have been made, it seems that as a result of Stieglitz's work we must eliminate from the list of gypsum deposits formed directly by the evaporation of sea-water or by evaporation in stream-fed inland basins all deposits that contain less than .5 per cent of calcium carbonate. Unless we are willing to assume an atmosphere with less carbon dioxide than at present, we must eliminate all deposits containing less than .9 per cent of carbonate.

Circulating water which has taken up gypsum disseminated in small quantities through beds traversed by the water is a primary factor in the formation of recent gypsum deposits. Gypsum so concentrated is often concentrated farther by the action of the wind and by evaporation in inland lakes.

Many gypsum deposits were originally anhydrite. The conditions which determine whether calcium sulphate will be deposited as gypsum or anhydrite are not fully understood, in spite of the work of van't Hoff and others. The chemist is seldom familiar with the field conditions which are associated with deposits of these minerals. If Udden is right in believing that extensive bodies of anhydrite in Texas have been formed as the result of reaction between magnesium sulphate in circulating solutions and calcium carbonate in the original sediment, the process may admit of broader application and may be applied to gypsum deposits which are distinctly bedded, yet which are so nearly free from calcium carbonate that they cannot be regarded as salt-pan deposits. Anhydrite formed might later be altered to gypsum.

[28] Mineral Industry, 1920, vol. 28, p. 333.

A Classification suggested

The following classification of extensive gypsum deposits according to origin is suggested:

A. Deposits formed by concentration of material disseminated through sediments:

1. In inland basins.

2. On the surface:

***a*, by springs;**

***b*, as efflorescence.**

***a′*, further concentrated by wind.**

***b′*, further concentrated in slight depressions by surface waters.**

3. In fissures, cavities, and as replacements.

B. By alteration;

1, of carbonates;

2, of anhydrite.

C. Deposits formed directly by evaporation of sea-water.

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ON METAMORPHISM IN METEORITES[1]

BY GEORGE P. MERRILL

(Presented by title before the Society December 29, 1920)

CONTENTS

INTRODUCTORY STATEMENT

For some years there has been a growing feeling among those who have given the subject consideration, that the peculiar structures found in many meteoric stones are due not to hasty crystallization from a molten magma, as has been argued by some, but rather to an origin through the metamorphism of tuffaceous materials. Statements to this effect, however, with the exception of those of Berwerth, Linck, Renard, Tschermak, and Wahl, noted below, have been given largely as matters of opinion, without a systematic presentation of the evidence pro and con. It is proposed here to bring together for record some of the more important data bearing on the subject and supplement them by results gained through my own studies.

To one at all versed in the study of meteorites, it is not necessary to remark that the existing structural features, both those of the constituent minerals and the stones as a whole, render it more difficult to trace with equal certainty changes which may be due to metamorphism than is the

[1] Manuscript received by the Secretary of the Society June 2, 1921.

This paper was read before the National Academy of Sciences April 25, 1921. It is printed with the permission of the Secretary of the Smithsonian Institution.

case in terrestrial rocks. The entire lack of such secondary minerals as are products of terrestrial metamorphism, the anhydrous nature of the constituents and their unoxidized condition, however, limit the possibilities, though they do not necessarily simplify the problem.

DISCORDANT NATURE OF OPINIONS RELATIVE TO ORIGINAL AND SECONDARY STRUCTURE

At the beginning of the discussion we are, however, faced with the discordant nature of the opinions held regarding the original nature and structure of the chondritic meteorites, with which we have principally to deal. In reviewing these it will, perhaps, not be necessary to go back beyond 1875, since the microscope and thin-section had even at this date scarcely come to their full efficiency.

Tschermak, in his discussion of meteorites and vulcanism,[2] says:

"Manche Meteoriten sind, von solcher Beschaffenheit, welche zeigt, dass sie durch einen allmäligen ruhigen Krystallisationsprocess gebildet werden, andere hingegen verrathen dadurch dass sie aus Bruchstücken zusammengefügt sind, die Wirkungen zertrümmernder Kräfte. Die meisten bestehen aus feinen Steinsplittern und runden Körnchen."

Practically the same views were repeated in 1885:[3]

"Dass bei den Meteoriten die Trümmerstruktur häufig sei, sehr viele bald deutlich, bald undeutlich klastisch sind und dass eine Anzahl der Meteorsteine ein vollstandig tuffartiges Ansehen haben. Auch in den eisenreichen Massen, wie in jenen von Brahin, Atacama, der Sierra de Chaco sind Bruchstücke von Krystallen verbreitet. Diese Erscheinungen stimmen mit der Ansicht von einer allgemein vulkanischen Bildung der Meteorite und entsprechen der zuvorgedachten Herkunft der Chondren."

With these views G. Linck was by no means in accord. Under date of 1878 he wrote:[4]

"Ich wiederhole nur und betone es, dass die Structur dieses Gesteines mit Tuffbildungen wenig oder nichts gemein hat, dass sie vielmehr auf Erstarrungaus dem Schmelzfluss hinweist, deren letzter Act sich sehr rasch vollzog, so dass ein verhältnissmässig leicht schmelzbares, den Krystallisationsrückstand bildendes Natronkalksilicat nicht mehr zur Krystallisation gelangen konnte."

A. F. Renard also wrote:[5]

"Je croyais pouvoir etendre a la generalite des meteorites chondritiques les

[2] Sitzb. der Akad. d. Wiss. II, Abth., April, 1875, p. 8.
[3] Mikros. Bischof. der Meteoriten.
[4] Ann. des k. k. Naturhist. Hofmuseums, Band xiii, 1878, s. 113.
[5] Bull. de la Classe des Sciences, Acad. Royal, Tome xxxvii, 1899, p. 539.

constatations que j'avais faites sur la structure de la meteorite de Lesves. J'avancais des lors que toutes ont ete soumises a des phenomenes analogues a ceux que nous montrent les roches terrestres metamorphisees par cataclase et je concluais que pour un grand nombre d'entre elles, on ne doit pas admettre, a cause de leur aspect clastique, qu'elles sont de natur tuface."

And again:

"Je rejette l'origine polygene qu'on avait attribuee a la generalite des meteorites chondritiques et que je les considere comme des roches cristallines qui ont subi l'action du metamorphisme dynamique."

And still further:

"Je me range donc sans hesiter avec ceux qui n'admettent pas que ces masses cosmiques soient des agglomerations de produits volcaniques incoherents." [6]

These diametrically opposed views, each of which had numerous supporters, can, as it seems to the writer, be explained only on the ground of an insufficient amount and variety of material for the study on the results of which the opinions were based. The fact would seem to have been overlooked that chondrules occur in greatest abundance and most perfect development in stones the tuffaceous nature of which is most pronounced. It is well nigh inconceivable, further, that structures like those shown in figure 1, plate 2, should have been produced through crushing forces, as argued. The fact that the same mineral occurs in such a variety of forms also shows conclusively that they must have originated under different conditions, which could not exist in closely adjacent portions of the same magma. This last has been pointed out by Borgström[7] and others. That a certain amount of internal crushing and disintegration has taken place in many stones is unquestionable and will be referred to later.

In that which follows I shall assume, then, that the tuffaceous nature of these stones and of the "Kugelchenchondrite" in general is no longer questioned. As to the possibility of such having undergone metamorphism, there is among those who have written on the subject less diversity of opinion.

Sorby, writing in 1877, says:[8]

"Taking, then, all the above facts into consideration, it appears to me that the conditions under which meteorites were formed must have been such that the temperature was high enough to fuse stony masses into glass; the particles could exist independently one of the other in an incandescent atmosphere, sub-

[6] The present writer can but feel that could M. Renard study the Cumberland Falls, Kentucky, stone he would modify somewhat his view.

[7] Trans. Roy. Soc. of Canada, 1904, p. 94.

[8] Nature (London, England), vol. 15, 1877, pp. 495-498.

ject to violent mechanical disturbances; that the force of gravitation was great enough to collect these fine particles together into solid masses, and that these were in such a situation that they could be metamorphosed, further broken into fragments, and again collected together."

Tschermak, in 1878, in discussing the origin of the border or rind around some of the chondrules of the Grosnaja stone,[9] ascribed to them a secondary origin, a product of a second rise in temperature (accompanied, it may be, by reducing vapors) not sufficient to produce fusion, but merely a structural modification of the superficial portions.

"Somit scheint es, dass die Rinde erst nachtraglich durch ein von aussen wirkendes Agens enstanden sei und zwar vermuthe ich, dass es eine Erhitzung, vielleicht unter gleichzeitiger Einwirkung reduzirender Gase, gewesen sei, Entstehung der blassen Rinde verursachte. Diese Erhitzung brachten keine Schmelzung hervor, sondern eine geringe Textur-Aenderung an der Oberflache."

It is not made quite clear in the above whether the reheating producing the structure changes was thought to have taken place after the chondrules became imbedded, as now in the tuff, or prior thereto. It is to be noted, however, that the Grosnaja stone is a black chondrite.

H. Reusch, in the summary of his description of the Tysnes and other Skandinavian stones,[10] says:

"(*a*) Die steinartige Substanz der Meteorite ist ursprunglich durch Abkuhlung von geschmolzenen Massen enstanden. (*b*) Die Chondrite sind Bruchstuckgesteine. (*c*) Bisweilen gewahrt man Zeugen einer wiederholten Desaggregation. (*d*) Einige Meteorite zeigen, dass sie einer starken Erhitzung (und chemischen Prozessen) nach ihrer ursprunglichen Bildung ausgesetzt waren)."

Berwerth, in 1901, after detailed study of the subject, wrote:[11]

"Nach allen diesen Erwagungen habe ich nur schliesslich die ansicht gebildet, das der chondrit ein durch umschmelzung metamorphosirter meteorischer Tuff. ist."

Wahl[12] explains the varying conditions of consolidation of chondritic stones on the supposition that as tuffaceous forms they have been subjected to heat of varying degrees of intensity and more or less sintered.

"Man könnte sogar die Chondrite ihrer Beschaffenheit nach in eine kontinuierliche Reiche einorden, beginnend mit den tuffähnlichen Mineralsplittermassen und endend mit den den Massengesteinen recht ähnlichen hochkrystallinen.

[9] Min. u. Pet. Mittheil, vol. 1, 1878, p. 153.

[10] Separat-Abdruck aus dem Nues Jahrbuch, für Mineralogie, Geologie, und Paleontologie. Beilageband iv, 1886.

[11] Centralblatt für Min. Geol. u. Pal., 1901, pp. 644.

[12] Zeit. Anorg. Chemic., vol. 69, 1910, p. 75.

"Aus dem oben Angeführten geht ohne weiteres hervor, das die Strukturenhaltnisse samtlicher chondritischen Meteorite der dan verstandlich werden konnen, wenn die entstehungsweise der Chonderstukturen und der krystallinen mit den Tuffastrukturen vergesellschafteten strukturen klargestellt würde."

The above quotations from the writings of well known authorities are sufficient to show the general trend of opinion on the subject.

In a systematic consideration of the problem it will be well to first refer briefly to structures common to the unaltered "Kugeln" (spherulitic[13]) chondrites and pass thence to crystalline spherulitic forms, and thence in turn to the white, gray, intermediate and holocrystalline forms, closing with a discussion of the methods by which such changes as may be observed have been brought about.

Structures common to unaltered spherulitic Forms

The spherulitic (Kugelchen) chondrites may be briefly described as consisting of numerous hard and well formed chondrules in varying proportions and conditions of fragmentation in a tuff-like ground, sometimes so loosely imbedded as to break away from it, or, again, in the crystalline forms, break with it. The structure as shown in the more tuffaceous forms (figure 1, plate 2) is but a disorganized mass of more or less fragmental materials in sizes from the finest dust to those sufficient for determination by the unaided eye. The chondritic structure is usually the most striking feature, and, indeed, some of them, as the ornansites, appear to be little more than aggregates of these peculiar bodies in all stages of fragmentation, imbedded in a fragmental base of their own debris. Concerning the fragmental nature of this base I have stated my belief that there can be no question, and for the present it can be passed over.

The chondrules themselves, with particular reference to their internal structure, need further notice, particularly the glassy and porphyritic forms. That these chondrules and chondroidal forms were not formed in the exact positions they now occupy should be, for the most part, a matter of common recognition, though as to their primary origin there may still be some question. It is, however, the view of the writer that the presence of these bodies is itself indicative of the tuffaceous origin of any stone in which they occur, whatever may now be its condition, crystalline or otherwise. This must certainly hold true where the chondrules are of a granular or porphyritic nature. In some instances, it is true, conditions are such as to raise a temporary doubt with the radiate or

[13] It is to be regretted that this term has found its way into meteoric nomenclature, as it is quite misleading. Kugelns are not spherulites and should not be confounded with them.

spherulitic forms, but in no instance have I seen a chondrule or chondroidal form under such conditions as to really satisfy me of its origin *in situ*. The occurrence of minerals of the same species under such a variety of conditions as presented by both "Kugels" and ground-mass, indeed, prohibits any other conclusion.

My views have been made the subject of a previous paper[14] and need only brief reference here. As there stated, those chondrules of glass and of cryptocrystalline and radiate enstatites are regarded as direct products of the cooling of molten drops, the porphyritic forms being considered mechanically derived fragments. Confining attention to these last, it will be observed that they consist of phenocrysts of the various silicates in a base ranging from a completely isotropic, undifferentiated glass (figure 2, plate 2) through fibrous to practically holocrystalline forms. The presence of this glass in the chondrules of the unaltered tuffaceous forms and its absence or rarity in others is significant and will be referred to later. Feldspar, if present, exists only as fragments, unless it be, as in the Dhurmsala stone, a constituent of a chondrule.

Structures common to crystalline spherulitic Forms

Passing to the so-called crystalline spherulitic chondrites, a marked difference in microscopic structure is readily observable, though there are very evident traces of a one-time tuffaceous nature in the form of still fragmental single crystals and chondrules, as in the Bluff (figure 3, plate 2), Menow, and Richmond stones. These forms are more compact than the *kugelchen* (spherulitic) forms, and the chondrules often break with the ground. Under the microscope, as in the case of the Hendersonville stone, that which seemingly represents the finely divided, almost dustlike interstitial material has become converted into a finely granular base in which the larger unaltered fragments and chondrules are imbedded. In my original description of this stone I say: The structure is not at all that of minerals crystallizing freely from a molten magma, but suggestive of a partial recrystallization of finely divided material as seen in metamorphic schists.[15]

Further study of the slides serves to confirm me in this opinion. An equally marked change is observable in the structure of the chondrules themselves, which carry little, if any, true glass, but in its place a gran-

[14] Proc. Nat. Acad. of Sciences, vol. 6, no. 8, 1920, pp. 449-472.

[15] Borgström makes a similar observation regarding the Saint Michel stone, a rhodite. He says: "Die structur is demgemass nicht hypidiomorphen sondern näher sich vielmehr einer panidiomorphen Strucktur von diesselben Art wie sie in vielen kristallinen Schiefen vorkommt."

ular aggregate of the silicates, as in figure 4, plate 2, where the appearance at once suggests a metamorphism of the glassy base in a porphyritic chondrule. Nowhere do I find any true undifferentiated glass, and there is but little maskelynite. The observations hold true of the stones (*Cck*) of Djati, Pengelon, Kernouve, Long Island, and others of this group. That these were derived from the tuffaceous forms would seem to be definitely settled by the facts stated, and particularly by the presence of the slightly altered and often more or less fragmental chondrules, which are so obviously foreign to their present position.

Structures common to crystalline Forms

The so-called crystalline chondrites consist of a firm, holocrystalline ground in which are imbedded occasional chondroidal forms. The most striking feature of the last mentioned is their lack of symmetry or perfection of outline, as compared with those in the tuffaceous varieties. (See figure 5, plate 2, and figure 1, plate 3, from the crystalline chondrite of Renazzo, Italy, and Estacado, Texas.) Another feature which is also found in the white, gray, and intermediate forms, yet to be noted, is the rarity of glass in the chondrules themselves and the obliteration of their apparent original outlines. In figure 2, plate 3, from the Ensisheim stone, it will be noted that the porphyritic chondrule merges gradually into the ground-mass, and that, further, the interstices of the phenocrysts are occupied not by glass, but by fine granular matter—a condition to at once suggest the crystallization of the glass base of a porphyritic chondrule during the general process of metamorphism which the stone as a whole has undergone.[16] Maskelynite and merrillite are almost universal characteristics of this group, as of the other altered forms described.

Structures common to white, gray, and intermediate Forms

Passing to consideration of the white, gray, and intermediate groups, one finds the same strongly marked differences in internal structure without change in mineral composition, though whether these differences are due to metamorphism or original crystallization is not always easily apparent. They show a ground distinctly cataclastic for the most part—a structure which is certainly in part due to crushing, as argued by Renard.

[16] The views thus above expressed are apparently fully in accord with those of Wahl, where he says: "Die Verfestigung und die Entstehung der kristallinen Struckturen der Chondrite läfst sich auf eine Erhitzung (Thermometamorphose) zurückführen, durch welche die Mineralsplitter und Chondren, je nach der Intensität der Hitzewirkung, mehr oder weniger kräftig aneinander geschweifst werden und die ursprünglich vorhandene Tuffstruktur verwischt wird."

Further, they are almost universally characterized by the presence of the colorless, sometimes isotropic, maskelynite, the calcium phosphate merrillite, and an occasional enwrapping and interstitial smoky glass, as in the Parnallee stone. It is among stones of these groups, also, that Berwerth, to whom we are indebted for the most satisfactory suggestions on the subject, found his "Netzbroncit" structure and such secondary changes as were to him indicative of meteoric metamorphism.

Causes of Variation in Structure

The question may well be asked if the variations noted are original or due to metamorphism. In his paper on the Zavid stone,[17] Berwerth, it will be recalled, described the interstices of the porphyritic olivines occupied by a "platyfibrous" form of bronzite ("Netzbroncit") which enacts structurally the rôle of the metal in a pallasite.

In a second paper he considers this with especial reference to metamorphism and draws the conclusion that this "Netzbroncit" is a secondary product due to a partial fusion and hasty recrystallization of the finer bronzite material in a chondritic tuff. The shattered condition of the individual constituents producing the cataclase structure so characteristic of meteorites of this class he considers due to this same reheating and sudden cooling process. With these conclusions the present writer takes no exceptions other than to state that he is unable to discover in slides of the white and gray chondrites at his disposal the netzbroncit structures developed to the extent and degree of perfection figured by Berwerth in his description of the Zavid stone, excepting in the porphyritic chondrules themselves, as noted above, and, further, he believes the cataclase structure to be due in part, at least, to crushing.

Moreover, he feels that there are other easily recognized criteria of metamorphism, mentioned below, of equal diagnostic value. I refer to the almost universal presence in the stones of these groups of the anomalous feldspar or feldspathic glass maskelynite and the equally anomalous calcium phosphate merrillite (figures 3 and 4, plate 3).

The name maskelynite, it will be recalled, was first given by Tschermak[18] to an isotropic constituent of the habit and composition of a labradorite feldspar occurring in the stone of Shergotty. The name has since been extended to cover a colorless interstitial substance, sometimes quite isotropic and sometimes faintly doubly refracting, of like

[17] Wissenschaft. Mittheil. aus Bosnien u. der Hersegovina, vol. 8, 1901. See also "Über die Structure des chondritischen Meteorstein. Central. für Min., etc., 1901, pp. 641-647.

[18] Sitzbericht der k. Akad. der Wiss., vol. 65, February, 1872, p. 127.

appearance and habit, and a common if not universal constituent of the chondritic meteorites, and in particular those of the white and gray chondrite groups.

Concerning the identity of the two substances Tschermak, after a full discussion,[19] says:

"Da dieser isotrope Gemengtheil genau dieselbe Form und Vertheilung zeigt wie der Plagioklas und im gewöhnlichen Lichte denselben Eindruck macht wie dieser, so glaubte ich aus dieser auffallenden Gleichheit der äusseren Form auf eine Gleichheit der chemischen Zusammensetzung schliessen und denselben für Maskelynite halten zu dürfen."

This view has been very generally accepted by subsequent workers.

H. Michel, in his "Die Feldspate der Meteoriten," [20] says:

"Das ganze Bilder Maskelynitleisten ist, wie schon Tschermak betont, wobei er sich auf die Autoritat von F. Becke stützt, das von Feldspaten, welch zuerst auskrystallisiert sind, Hohlräume und Zwickel freigelassen haben, in denendann der Pyroxen krystallisierte, derart, dass wohl auch die Bildungsperioden ineinander übergriffen. Es finden sich nämlich bisweilen Partien mit einer Art Eutektstruktur, bei denen sich über das gegenseitige Alter von Pyroxen und Maskelynite nichts aussagen lasst."

The identity of the mineral is further supported by the refractive indices as given by Michel in the paper quoted and as determined by myself[21] in the stones of Hartford and Ness County.

It will be recalled that in the case of the Hartford stone (a white chondrite) the questionable mineral was not merely slightly doubly refractive, but gave by the immersion methods indices of 1.54–1.545, and that in a few instances I was able to discover still remaining evidences of polysynthetic twinning, indicative that the metamorphism had not been sufficient to completely destroy the original structure. In the white chondrite of Colby, Wisconsin (figure 3, plate 3), maskelynite is rarely completely isotropic, but is unequally anisotropic throughout.

It would seem that the question of the derivation of maskelynite from a plagioclase and the identity of these minute interstitial forms with that of the Shergotty stone might be considered as settled. Nevertheless, authorities are not wholly in agreement on the subject. Groth, it will be recalled, regarded the mineral as an independent species, related to leucite, which had become anomalous in its refracting qualities through pressure or a rise in temperature. This view has not been generally accepted.

[19] Die Meteoriten, etc., p. 18.
[20] Tschermak's Min. und Pet. Mitteil., vol. 31, 1912, p. 584.
[21] Mem. Nat. Acad. Sci., vol. 14, 1919, pp. 5-7.

Linck,[22] in his discussion of the mineral in the Meuselbach stone, says:

"Ich wiederhole nur und betone es, dass die Structur dieses Gesteines mit Tuffbildungen wenig oder nichts gemein hat, dass sie vielmehr auf Erstarrung aus dem Schmelzfluss hinweist, deren letzter Act sich sehr rasch vollzog, so dass ien verhaltnissmassig leicht schmelzbares, den Krystallisationsruckstand bildendes Natronkalsilicat nicht mehr zur Krystallisation gelangen konnte."

Borgström,[23] as late as 1904, wrote:

"The occurrence of the maskelynite between the chondrules and crystals of olivine and enstatite and close to troilite and nickel-iron forbids an interpretation of it as a refused feldspar. The maskelynite in the meteorite from Shelburne is a true mineral species and no alteration product."

With these opinions the present writer can by no means agree. In my own mind there are but two possible alternatives regarding the substance: Either (1) the stones in which it occurs are direct products of the cooling and crystallization of a molten magma, in which case the maskelynite *may*, perhaps, be a residual feldspathic glass or an altered feldspar, or (2) they result from the accumulation and compacting of already solidified particles—that is, are clastic or tuffaceous—in which case the maskelynite *must* be secondary and due to metamorphism. Its form and mode of occurrence admit of no other conclusion,[24] as noted by Tschermak. Indeed, the habit of this substance in occupying the irregular interstices of the magnesia-iron constituents and its common occurrence in the white, gray, and intermediate chondrites, together with its almost entire absence in the unaltered "kugelchen" forms, is one of the strongest arguments in favor of its secondary origin, through the metamorphism of a tuffaceous stone of the type of Allegan or Bjürbole. Borgström's objection to this, based on its occurrence in close juxtaposition to troilite and nickel-iron, I can not regard as well founded, since both of these substances are themselves secondary (see page 412) and may have been formed at an entirely different period and under different conditions. The fact that either substance occurs not infrequently enwrapping a chondrule, would suggest at least that they were the very latest of the products of solidification.

It is to be noted further that this "glass" never shows the slightest traces of the shattering which is so characteristic a feature of the other minerals and which is variously ascribed to pressure or abrupt changes

[22] Ann. k. k. Naturhist. Hofmuseums, Band 13, 1898, s. 113.
[23] Trans. Royal Soc. of Canada, 1904, pp. 91-92.
[24] It is a trifle singular that Borgström, after having made the statement quoted above, should describe the Shelburne stone as a veined gray chondrite—that is, as composed of compacted, already solidified particles. The two statements, as I view this matter, are contradictory and irreconcilable.

in temperature. This, as I view it, should effectively dispose of the idea of its being an original residual glass. It is a later product and was unmistakably the last of the silicate constituents to solidify, and, with the possible exception of those involved in the deposition of the metal and sulphides, represents the closing act in the series of changes through which the stone has passed.

There remains to be noted yet one other structural feature characteristic of this group, which may be regarded as secondary and of metamorphic origin. In the Knyahinya stone (a gray chondrite) the chondrules are sometimes surrounded by a fine granular border (figure 1, plate 4), which seemingly represents the metamorphism of an interstitial dust-like material. The same feature, in a more pronounced form, is shown in sections of the Mezö Madaras, Parnallee (figure 2, plate 4), and Richmond stones, the first two gray chondrites and the last a crystalline spherulitic form. I am convinced that this is likewise of a secondary or metamorphic nature, a product of heating sufficient to affect (sinter) the finer interstitial material, but not sufficient to obliterate the original fragmental structures. I will again refer to this in discussing the agencies of metamorphism.

Agencies of Metamorphism

Assuming the features above described are of secondary origin and due to metamorphism, the question arises as to how this metamorphism has been brought about. Before entering on a discussion of this it will be well to again call attention to the entire lack in the meteorites of such secondary and more or less hydrated minerals as are common characteristics of metamorphosed terrestrial rocks.

The field of speculation is at once narrowed, though not necessarily simplified. It can be safely stated, however, at the outset, that the changes noted have taken place in an atmosphere free from moisture and influences promoting oxidation. Evidently they were limited to dry heat and pressure.

Perhaps one of the most striking features of the chondritic meteorites is their paucity, outside of the chondrules, in a residual, undifferentiated glass base, and it is a most singular fact that those who advocate the "hasty crystallization" origin of these stones have failed to realize a condition so fatal to their conclusions.

I do not agree with Weinschenk and others, that in certain stones like Chassigny, Ensisheim, Farmington, Mezö Madaras, and Parnallee, glass is so abundant as to form a network in which the other minerals are im-

bedded. Ensisheim, which forms Weinschenk's "Typus I" of normal stones, as shown by my slides, instead of consisting of a glassy base with skeleton crystals or "mit lichtem glas und massenhaften Bronzitskeletten in der Ground-mass,"[25] is an almost holocrystalline, though very irregularly granular, aggregate, with occasional small interstitial areas of colorless material which inclose, usually, small rounded granules of enstatite or olivine and, as a rule, polarized slightly in light and dark colors, as the stage is revolved. This has all the characteristics and habit of maskelynite, which I believe it to be. Nowhere in this or the other stones mentioned do I find appreciable traces of an original undifferentiated glass base, such as might result from the rapid cooling of an igneous magma.

As for the "glassy" border surrounding the chondrules of the Parnallee and other stones of this group, I need only call attention to the fact that, as the stones are plainly fragmental, the border can not be other than secondary. As a matter of fact, an examination with a high power shows that the border is not a true glass, but rather a semivitreous material, the result of an alteration or imperfect sintering of the finer portion in the ground. That this may have been the result of temperature changes is made sufficiently evident by a comparison of figure 2, plate 4, that of a "glass" bordered chondrule in the Parnallee stone, and figure 3, from a section from a fragment of the Allegan stone, a spherulitic chondrite, that had been heated in a gas blast furnace to the point of incipient fusion on the outer surface. The "glassy" border is identical in appearance in both instances. In short, I consider the "glass" in all these cases to be secondary and due to metamorphism, incidental to a partial fusion of clastic material.

It may be well to note, as bearing somewhat on this reelevation of temperature and sintering problem, that the Farmington, McKinney, and Renazzo stones, in which are conspicuous traces of "glass," are black chondrites, such as Meunier[26] has contended and as subsequently shown in our own laboratory,[27] can be produced by heating ordinary chondritic stones in an atmosphere poor, if not wholly lacking, in oxygen.[28]

[25] Sitz. der k. k. Akad. Math.-Phys. Classe. Munchen, 1899, 1 Heft.

[26] Compte Rendu, Paris Acad., vol. 71, 1878, p. 178.

[27] Proc. Nat. Acad. of Sciences, vol. 4, 1918, p. 178.

[28] I do not agree with Kunz and Weinschenk as to the origin of the Farmington stone. They say, in the American Journal of Science, volume 43, 1892, page 67: "All these (minerals) are entirely enveloped in an opaque, evidently glassy, magma. . . . It is undoubtedly not a polygenius conglomerate, but was rapidly formed out of the fluid glassy magma." Not merely does the stone contain abundant fragmentary chondrules, as would be impossible were it a direct process of cooling from a molten magma, but the amount of glass is really very small and might much more readily be accounted for as above.

That a rind, or border, indicative of a second rise in temperature is to be found about some of the chondrules of the Grosnaja stone was noted by Tschermak. This stone is, however, a black chondrite, which feature in itself is considered as due to heat. More enigmatical are such forms as are shown in figure 5, plate 4, from the Beaver Creek chondrite, where there is an irregular outer border strongly suggestive of a secondary growth. If such is the case, however, it is questionable if the same must not have taken place at some prior, earlier, stage of meteorite history, since the stones are both almost wholly unaltered spherulitic ("Kugeln") chondrites.[29]

Tschermak, in his description of the Alfianello and Mocs stones,[30] the first an intermediate and the second a white chondrite, states that in the Alfianello he finds both isotropic and doubly refracting granules, and some that appear but partially isotropic, transition phases, as it were (figure 1, plate 5):

> "Dies führt dazu, die isotropen Körner als umgeschmolzenen, also durch Erhitzung isotrop gewordenen Plagioklas anzusehen."

In Mocs, plagioclase occurs in the body of the stone, but no maskelynite. In the fused crust, maskelynite alone is found.

H. Michel,[31] whose excellent work on the feldspars of meteorites is most helpful, notes the indications of thermo-metamorphism in the Juvinas stone, a eukrite, and that the pyroxenes have become more or less granulated and filled with glass inclusions. The clear border or zones about the plagioclase, regarded as due to this cause, are free from inclusions, less strongly doubly refracting than elsewhere, and have variable angles of extinction. He thinks that this alteration was brought about at a temperature lower than that of the fusion points of the pyroxenes (1265°), resulting only in a reduction of the feldspars to a condition of viscosity. He notes further that the white chondrites are rich in plagioclases which are lacking in the black, and that the intermediate and gray chondrites occupy a position in this respect intermediate of the two. This indirectly confirms Meunier's opinion as to the origin of these black forms.

Accepting the fusion points as given by Doelter[32] (bronzite, 1310°–1400°, and anorthite, 1250°), it is not difficult to conceive of metamorphism due wholly to heat, as advocated by Tschermak and as is appar-

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[29] I do not agree with Brezina (Die Meteoritensammlung, 1895) in classing this Beaver Creek stone as a *crystalline* spherulitic chondrite (*Cck*).

[30] Die Meteoriten, etc.

[31] Tschermak's Min. und Pet. Mitteil., vol. 31, 1912, pp. 650 et al.

[32] Handbuch der Minerchemie, vol. 1, pp. 658-659.

ently so evident in the mesosiderite of Estherville, Iowa. In my recent description of this stone[33] I have shown that in the process by which a clastic mixture of pyroxene, olivine, and feldspar fragments was converted into one essentially holocrystalline, the larger feldspar fragments remain in all gradational forms from those unaltered and still retaining their twin striations to those still only in part doubly refracting but quite structureless, as seen under the microscope, and in some cases with an unaltered nucleal center merging into a clear border, a plain product of secondary fusion (see figure 5, plate 3). Facts like these and the occurrence in the Mocs stone of the maskelynite only in the fused crust should seemingly be accepted as proving beyond a question the secondary origin of the mineral through heat metamorphism, though that there are objections is noted later.

The presence of the secondary form of phosphate, to which Dr. E. T. Wherry has seen fit to give the name of merrillite,[34] I consider equally indicative of metamorphism by heat. It will be recalled that this form of the mineral was first described by me in 1915[35] as an almost colorless constituent occurring with irregular outlines in the ground-mass of various stones and with optical properties too obscure for determination, but the chemical nature of which was solved by micro-chemical methods. The occurrence is similar to that of the maskelynite and leaves no question as to its being one of the last minerals to solidify, even if not of secondary origin (see figure 4, plate 3). Like the maskelynite, the mineral is found to be of almost universal occurrence in the white, gray, and other chondrites of assumed metamorphic nature.

Assuming, as apparently one must, the correctness of both the observations and conclusions drawn relative to the origin of the maskelynite, as given in the previous pages, the question naturally arises, Why are not similar forms found in our terrestrial rocks? Assuredly conditions, as along certain contact zones, must somewhere have been favorable; yet, so far as the writer is aware, not a single example has been reported.

Berwerth is inclined to draw a comparison between these forms and some produced in terrestrial rocks through contact metamorphism, and refers explicitly to the peculiar "geflossene" form of pyroxene granules in certain silicate rocks and the "Wachsthumformen" of the andalusite in hornstone. I am not at present ready to comment on this. I can not, however, agree with him when he says (page 645):

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[33] Proc. U. S. Nat. Mus., vol. 58, 1920, pp. 365-370.

[34] American Mineralogist, vol. 2, no. 9, 1917.

[35] Proc. Nat. Acad. of Sciences, vol. 1, p. 302. See also Amer. Jour. Sci., vol. 43, 1917, pp. 322-324.

"Kugelbildungen erscheinen ja auch auf unserer Erdeuberall dort wo naturliche oder auch Künstliche Glasflüsse einer rasche Abkuhlung ausgesetz sind."

As a matter of fact, the "Kugels" of artificial glasses are not chondrules, but spherulites.[36]

So far as is known, no systematic attempts at an artificial production of the material under conditions at all satisfactory have as yet been made. Fragments of the Mount Hope, Maryland, gabbro, described by Williams[37] as composed essentially of plagioclase, diallage, and hypersthene, with secondary hornblende, were roasted in a gas blast furnace in the museum laboratory until reduced to molten blebs with cores of still unmelted material. Examination in thin-section showed the pyroxene and amphibolic minerals to have fused to a black glass, while the feldspar (bytownite) was nearly or quite unaltered. A mixture of finely pulverized bytownite from Nürodal, Norway, and a light-colored diopside from Siberia yielded a like result. The crudity of these attempts prevents, however, the acceptance of the results as conclusive.

It is likely that some other agent than heat with or without reducing gases may have been efficacious in bringing about this metamorphism; and, if this agency were pressure, are there visible proofs of its action? It may be recalled that in my description[38] of the stone from Cullison, Kansas, a hard, compact stone susceptible of a polish, but which, nevertheless, I classed as spherulitic chondrite, I referred to an "indistinct wavy banding" visible on a polished surface, which I thought comparable with the "schlieren" structure of terrestrial rocks; in other words, that it indicated a one-time shearing movement which was, of course, due to pressure (figure 3, plate 5). Little evidence of such a force manifesting itself on the individual minerals and microstructure is available in the literature. That which is here presented is largely the result of my own observations. In many chondritic stones there are well marked instances in which the finer clastic interstitial material seemingly has been formed by the more or less complete crushing of the larger forms, productive of what Cohen calls a "pseudotrümmerstructur." Illustrations of this are not rare.

In the Dhurmsala stone shown in figure 2, plate 5, the large crystal of enstatite near the center has been crowded against the radiate chondrule, fractured, and in places reduced to fragments. Here, as in many other cases, however, it is difficult to say just what portion of the fine inter-

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[36] Pirsson: Amer. Jour. Sci., vol. 30, 1910, pp. 97-114.
[37] Bull. 28, U. S. Geol. Survey, 1886.
[38] Proc. U. S. Nat. Museum, vol. 44, 1913, p. 327.

stitial material is to be regarded as original detritus and what produced in place by attrition.

Again, in the Parnallee stone are frequent occurrences like that shown in figure 1, plate 6, where a porphyritic chondrule has been crowded against a fragment of a twinned pyroxene, bending it to the point of fracture. Still other illustrations of this nature are afforded by the recently described Troup stone, an intermediate chondrite.[39] Thin-sections of this show numerous large and small single individual fragments of olivine and enstatite with torn and ragged borders and no remaining traces of crystal faces, completely surrounded by finely granulated clastic material with interstices filled with maskelynite.

No other conclusion can be drawn, as it seems to me, than that these particles are clastic, and the only question relates to their origin. Are they due to a local crushing and differential movement among themselves, or are they tuffaceous and altogether foreign to their present position? In any case, since their consolidation the stones have been subjected to a rise in temperature sufficient to fuse the feldspathic material which on cooling congealed as a glass rather than in crystal form. This is illustrated in the section of the Alfianello stone, an intermediate chondrite (figure 1, plate 5).

These and like occurrences, it should be noted, are interpreted by Renard as militating against the possibility of a tuffaceous origin for the stones. He calls attention to the frequent slight amount of displacement of the shattered particles and correctly argues that such a condition would be practically impossible and wholly improbable were the materials transported as loose detrital tuffs. He therefore argues that the stones of these groups were once crystalline and owe their present cataclastic structures to the dynamic agencies, as already noted.

In reply to this, attention need but be called to the fact that the displacements in these particular instances are indeed too slight to account for the tuffaceous structure in the "Kugelchen chondrite" shown in figure 1, plate 2. They are secondary and of minor importance and have, in my belief, no bearing on the original nature—crystalline or fragmental—of the stone.

Berwerth,[41] it needs be stated, was opposed to Renard's view. The presence of the "Netzbroncit" binding material he thought a direct contradiction to the idea of pressure metamorphism.

"Such a possibility [he wrote] can only be accepted if one considers the netzbroncit as a product of mechanical attrition, which theory can not be ad-

[39] Proc. U. S. National Museum, vol. 59, 1921, pp. 477, 478.
[41] Op. cit., p. 14.

vanced, considering the manner of growth. The laminated broncit (netzbroncit), acting as a cementing substance, is crystallized from a fused magma, and therefore the thought of a secondary cataclastic structure caused through pressure is entirely eliminated. The existing cataclastic disruptions can be sufficiently explained by a sudden change of temperature to which the meteoric substance was exposed when in this process of melting."

The objections of both Renard and Berwerth, as it seems to the writer, are done away with if we consider the shattering as incidental to the general compression to which the stones have been subjected, as having taken place prior to the formation of the netzbroncit and, above all, to that of the maskelynite. It must be recalled that neither of these minerals show any trace of mechanical distortion, unless it may be that indicated by a slight optical anomaly. The maskelynite in no case that has come under my observation shows any trace of the fracturing so constant a character of the olivines and pyroxenes. It was obviously the last mineral to solidify, and its production was the closing act in the series of changes and conditions to which the stones have been subjected.

Although the interpretation I have put in the foregoing pages on certain structural details may in some cases seem open to question, nevertheless the facts as given, it is thought, fully substantiate the idea of metamorphism in meteorites—that the crystalline forms were derived from the tuffaceous, rather than the reverse. Whatever lingering doubts one may have are due mainly to the lack of certain incidental effects which seemingly should have been manifest. The most striking of these discrepancies is the small amount of true magmatic glass found in any of these forms. It would seem strange that were this metamorphism due so largely to dry heat, as is apparent, occasional forms should not be met with that are wholly vitreous or that, at least like some of our modern lavas, are largely glass with varying proportions of phenocrysts. Any argument based on this feature may be used, however, with equal force against the idea of direct cooling from a molten magma. The suggestion that the so-called tektites may be representatives of the missing glassy forms is ruled out on chemical grounds.

A brief summary of the matter in the foregoing pages may be set forth as below:

I. Evidence of metamorphism mainly through dry heat.
   (1) The presence of interstitial maskelynite and merrillite.
   (2) The "glass" border about the kugel.
   (3) The absence (in the metamorphosed forms) of glass, other than maskelynite, in the chondrules and the presence in its place of fine granular crystalline matter.

(4) The "Netzbroncit" of Berwerth.

II. Evidences of metamorphism by pressure.

(1) The granulation of the radiate enstatite chondrules and their gradual merging into the ground-mass.

(2) The distortion, and at times almost complete obliteration, of chondrules of any kind.

(3) The crushed condition of many of the crystalline particles.

(4) The more compact condition of the stone, with chondrules at times so finely imbedded as to break with the matrix.

The most obvious of the above characteristics are the absence of well developed chondrules in the crystalline chondrites and the presence of maskelynite. As elsewhere stated, it is questionable if the presence of a chondroidal form of any kind may not be regarded as indicative of the one-time tuffaceous nature of the stone in which it occurs. The writer is at present so inclined to regard it. Indeed, he can not conceive of a chondrule of the radiate enstatite or porphyritic form resulting from direct secretion in a molten magma.[42]

There remains for consideration the metallic constituent of stony meteorites, and this with particular reference to its origin and connection, if any, with the subject under discussion.

That the metal is secondary in its relation to the silicate constituents has often been insisted on by the present writer[43] and others, and its original source variously suggested as a product of reduction from iron-rich silicates or more probably, in the view of the writer, a ferrous chloride. Its apparent secondary nature is shown in figure 3, plate 6, from the gray chondrite of Parnallee. In this and like cases the metal was apparently precipitated around the fragment, causing it to appear in the section as a collar or ring. The manner in which it penetrates into the interstices of the ground indicates its deposition since the granule occupied its present position. The same feature is common in the Cullison, Kansas, stone, and as this has suffered little or no metamorphism the assumption is fair that the two agencies, metamorphism and deposition, are quite independent of one another. A still better illustration than that furnished by either of the above is shown in figure 4, plate 6, from the Cumberland Falls breccia. It will be noticed here that the metal occurs in plates so thin as to appear on a polished surface as mere threads, at times scarcely visible, which penetrate the interstices, often bifurcating

[42] "On chondrules and chondritic structures:" Proc. Nat. Acad. Sciences, vol. 6, August, 1920, pp. 449-472.

[43] See papers on Cumberland Falls and Estherville meteorites, cited elsewhere; also Daubrée, Geol. Experimentale, pp. 520-522.

and completely enwrapping a chondrule or crystal granule, as the case may be. It is not possible that the temperature during the period of deposition remained sufficiently high to hold the metal in a condition so liquid as to penetrate the stone to this extent. The only alternative is that it was derived from some easily reducible vapor or solution of greater penetrative power and at a probable lower temperature.[44] It is noticeable, further, that there is in these cases no recognizable corrosion of the silicates, even where the metal occurs in much larger quantity, a matter to which I have elsewhere[45] called attention. It is still further to be noted that in the case of the Cumberland Falls stone the metal occurs also in form of a thin plate lying between the enstatite breccia and the dark chondritic fragment it incloses. In this case at least a portion of the metal was certainly deposited subsequent to the brecciation and commingling of the fragments.

A study of a large number of analyses shows, however, no recognizable relationship in the percentage amount of metal and degree of metamorphism.

The tuffaceous meteorites, as previously announced, are considered unquestionably of volcanic origin. That a ferrous chloride is a constituent of volcanic emanations is a matter of common knowledge. The products from such emanations from terrestrial volcanoes naturally appear largely in the form of oxides, but in an oxygen-free atmosphere, and particularly one containing free hydrogen, one is justified in assuming the reaction $FeCl + H = Fe + HCl$. Meunier has shown[46] that this reaction may take place at a temperature not exceeding 400° centigrade. I can therefore see no reasonable objection to the assumption that such an origin as outlined may be ascribed to the metal in stony meteorites. This idea, I need scarcely state, is not wholly new.

Summary of Conclusions

The chondritic meteorites are regarded as of a tuffaceous origin and their crystalline structure, where such exists, as due to metamorphism in which both heat and pressure have taken part. It is pointed out that the most perfect chondroidal forms are found only in those meteorites the fragmental (tuffaceous) nature of which is most prominent, and that

[44] Iron melts at about 1500° centigrade, while the figures I have quoted on page -- for the fusing points of the silicates range from 1250° centigrade to 1400° centigrade. The conclusion is obvious.

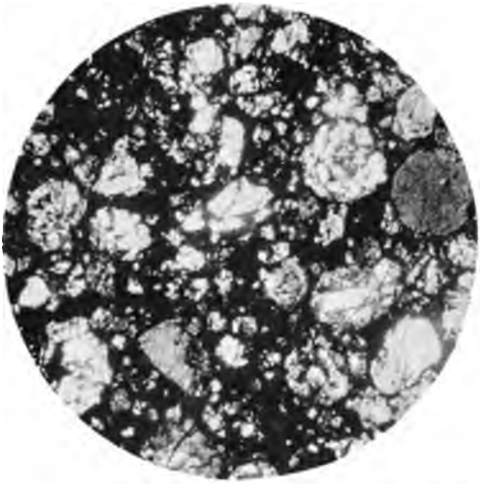
[45] On chondrules, etc. Proc. Nat. Acad. of Sciences, vol. 6, no. 8, p. 470. The brecciated pallasitic forms, like those of Admire and Eagle Station (Rökiky group), show in an even more marked degree the lack of any corrosive power of the metal.

[46] Meteorites, Paris, 1884, p. 346.

they grow less perfect, more highly altered, as they pass into crystalline forms. It is, therefore, suggested that the mere presence of a chondrule in a meteorite, whatever its present condition, is indicative of a tuffaceous origin. The clear, limpid interstitial glass, sometimes isotropic and sometimes doubly refracting, is considered feldspathic (maskelynite) and as due to metamorphism. Further, it is shown to have been the last mineral to congeal and is believed to represent the closing act in the series of changes through which a stone has passed. The dark "glassy" interstitial material is considered likewise secondary, a result of a partial refusion and alteration of the finer interstitial material, accompanying a secondary rise in temperature. It is shown that the crushing of the individual constituents, while unquestionably efficacious in the development of a cataclastic structure, is a minor feature and without bearing on the question of the original tuffaceous nature of the stone. The metal is shown to be of secondary origin and its introduction subsequent to the consolidation of the stone in its present form and quite independent of the metamorphism.

The foregoing investigations, I may state, have been carried out with other ends in view than have been thus far indicated. It was felt that in following up the life history of a meteorite—noting its original condition and the changes that have taken place—some light might be thrown on its possible source and subsequent wanderings, particularly as we are able to realize the conditions under which the changes have been brought about. To illustrate: The chondritic meteorites have been shown to be a result of explosive volcanic activity. Now, vulcanism is essentially a surface phenomenon; but the meteorites invariably carry unoxidized, but easily oxidizable, materials—chlorides and metals. Their formation, on the assumption that these are primary, must, then, certainly have taken place in a dry and oxygen-free atmosphere. Our earth as the maternal source of meteorites is, then, at once ruled out, unless their birth be relegated to that far period of early youth when no atmosphere as we now know it existed. The rest of the story is not yet so clear. The iron, as I have stated, is secondary and probably owes its reduction to metallic form to the influence of hydrogen. Where such an atmosphere exists is for the astronomer to tell us. The fact that the stones show the effect of heat and rapid cooling may, perhaps, be accounted for on the cometary hypothesis—that their brief stay in the proximity of the sun was followed by so rapid a retreat as to prevent a complete recrystallization of the fused material.

If the investigation fails to point to a complete solution of the problem, it may at least serve a useful purpose in limiting the range of hypotheses.



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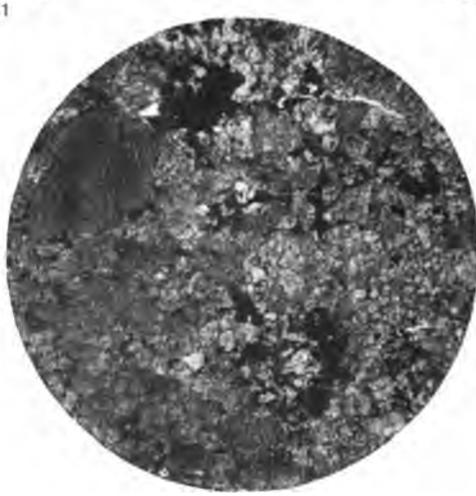

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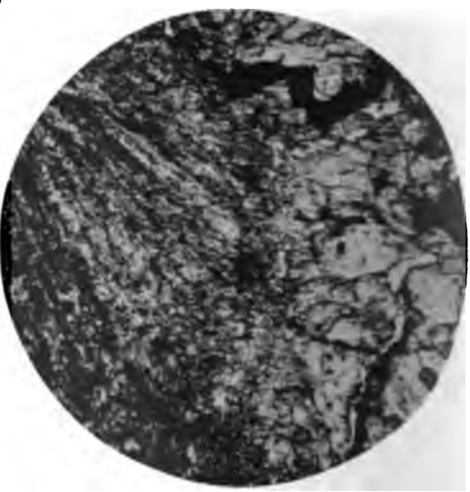

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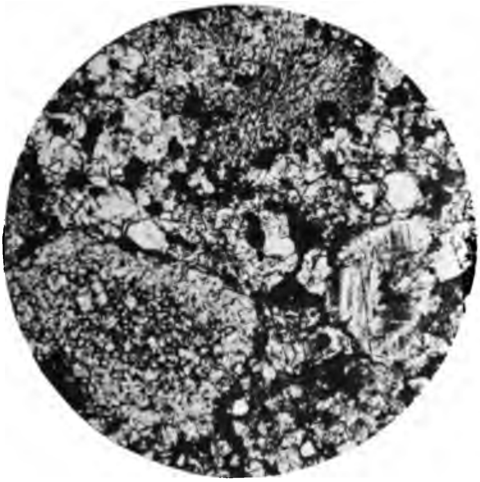
PHOTOMICROGRAPHS OF METEORITES



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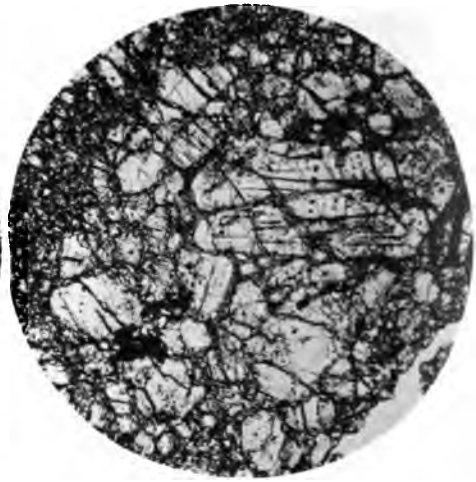

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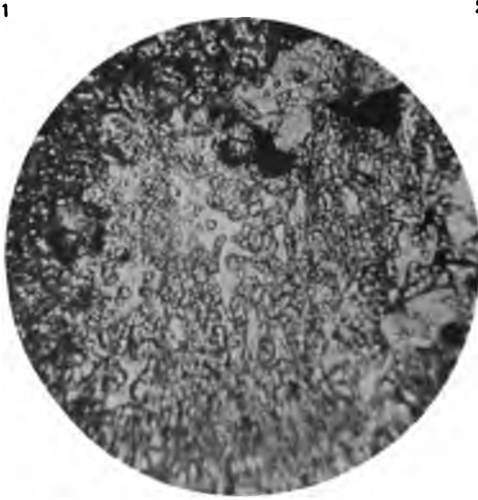

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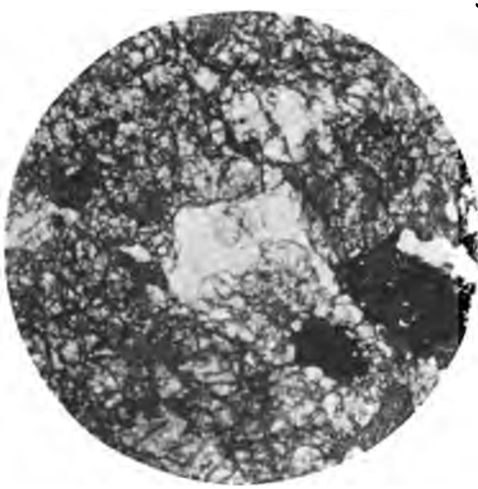

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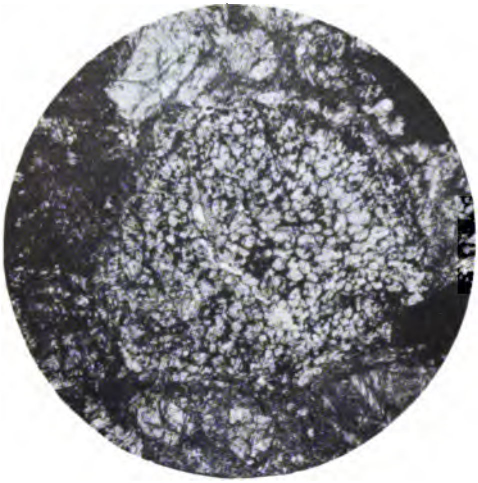
PHOTOMICROGRAPHS OF METEORITES



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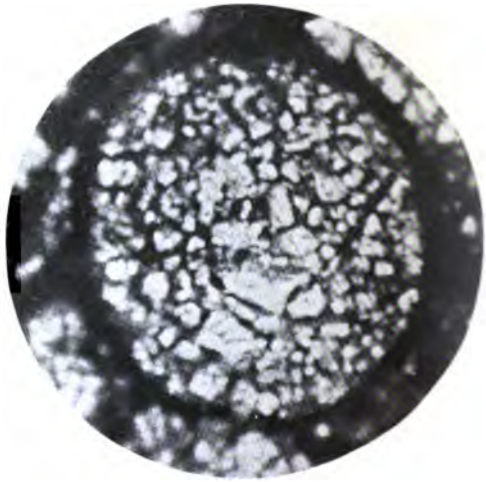

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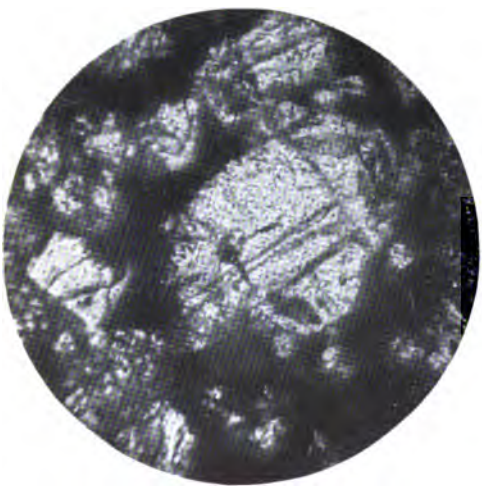

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PHOTOMICROGRAPHS OF METEORITES

Explanation of Plates

Plate 2.—*Photomicrographs of Meteorites*

Figure 1.—Photomicrograph from a thin-section of the Selma, Alabama, stone, showing fragmental chondrules of several distinct types which plainly are not due to simple crushing in place, but foreign to their present environment.

Figure 2.—Porphyritic chondrule with glass base from the tuffaceous (*Cc*) chondrite of Tennasilm, Russia.

Figure 3.—Photomicrograph of thin-section of the crystalline spherulitic chondrite (*Cck*) from Bluff, Texas. Its original tuffaceous nature is made evident by the presence of abundant fragmental and distorted chondrules.

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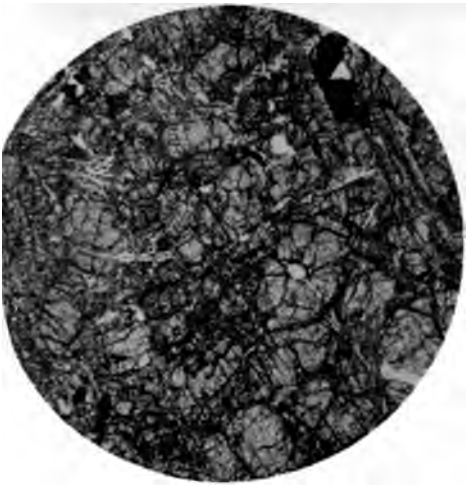

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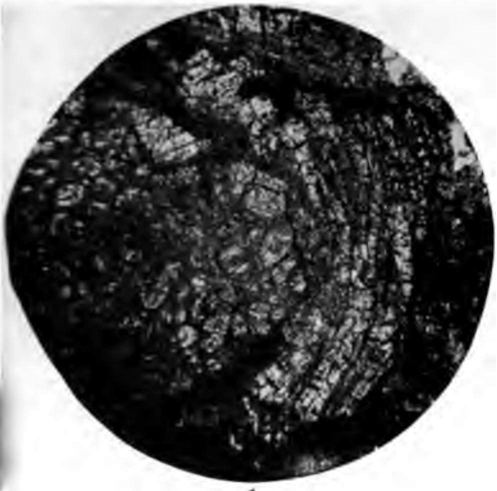
PHOTOMICROGRAPHS OF METEORITES



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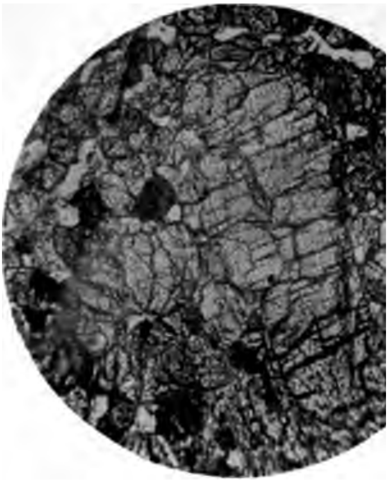

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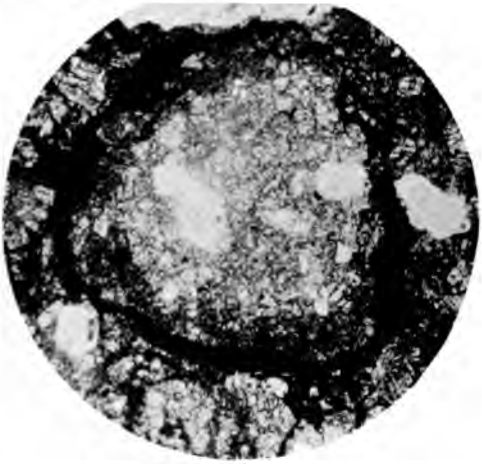

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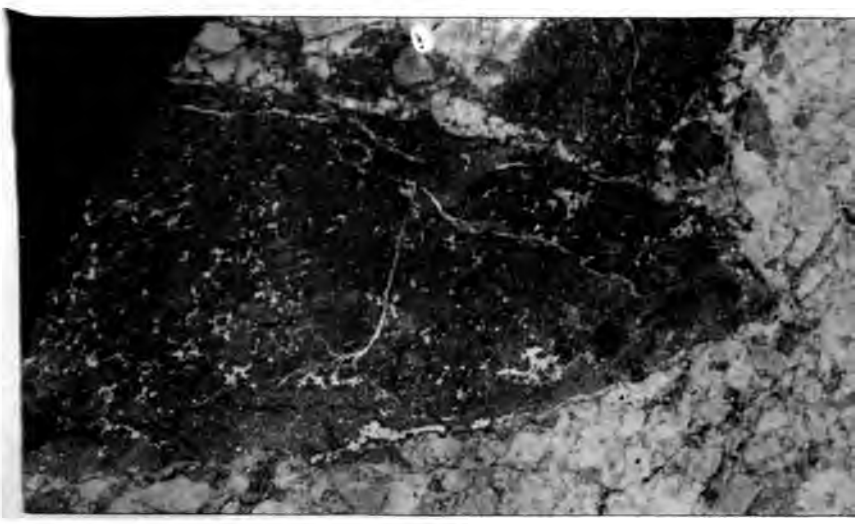

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PHOTOMICROGRAPHS OF METEORITES

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 32, PP. 417-428 DECEMBER 1, 1921

SOLITARIO UPLIFT, PRESIDIO-BREWSTER COUNTIES, TEXAS[1]

BY SIDNEY POWERS

(*Read before the Society December 29, 1920*)

CONTENTS

INTRODUCTION

The Solitario is a circular dome 5 miles in inside and 7 miles in outside diameter, situated 60 miles south of Marfa, west Texas, in both Presidio and Brewster counties (figure 1). It is in the trans-Pecos section, 9 miles in a straight line from the Rio Grande, on the western side of the "Big Bend" in the river and 25 miles east of Presidio. Occasional ranches are scattered through this barren mesquite desert, but few are near the highways. Military roads have been constructed from Marfa to Lajitas past the Solitario and to other outposts. There is a wagon road from the Lajitas road past McMahon's ranch into the north end of the uplift.

Although the Solitario is shown on the topographic sheet of the Terlingua quadrangle, United States Geological Survey (figure 1), and although it has been visited by several geologists, including G. K. Gilbert, J. A. Udden, and R. T. Hill, nothing has ever been written about it.[2]

[1] Manuscript received by the Secretary of the Society May 17, 1921.

[2] It is shown on the "Geological map of a portion of west Texas," by B. F. Hill and J. A. Udden, University of Texas Mineralogical Survey, 1904. References to the Big Bend country are: J. A. Udden, A sketch of the geology of the Chisos country, Brewster

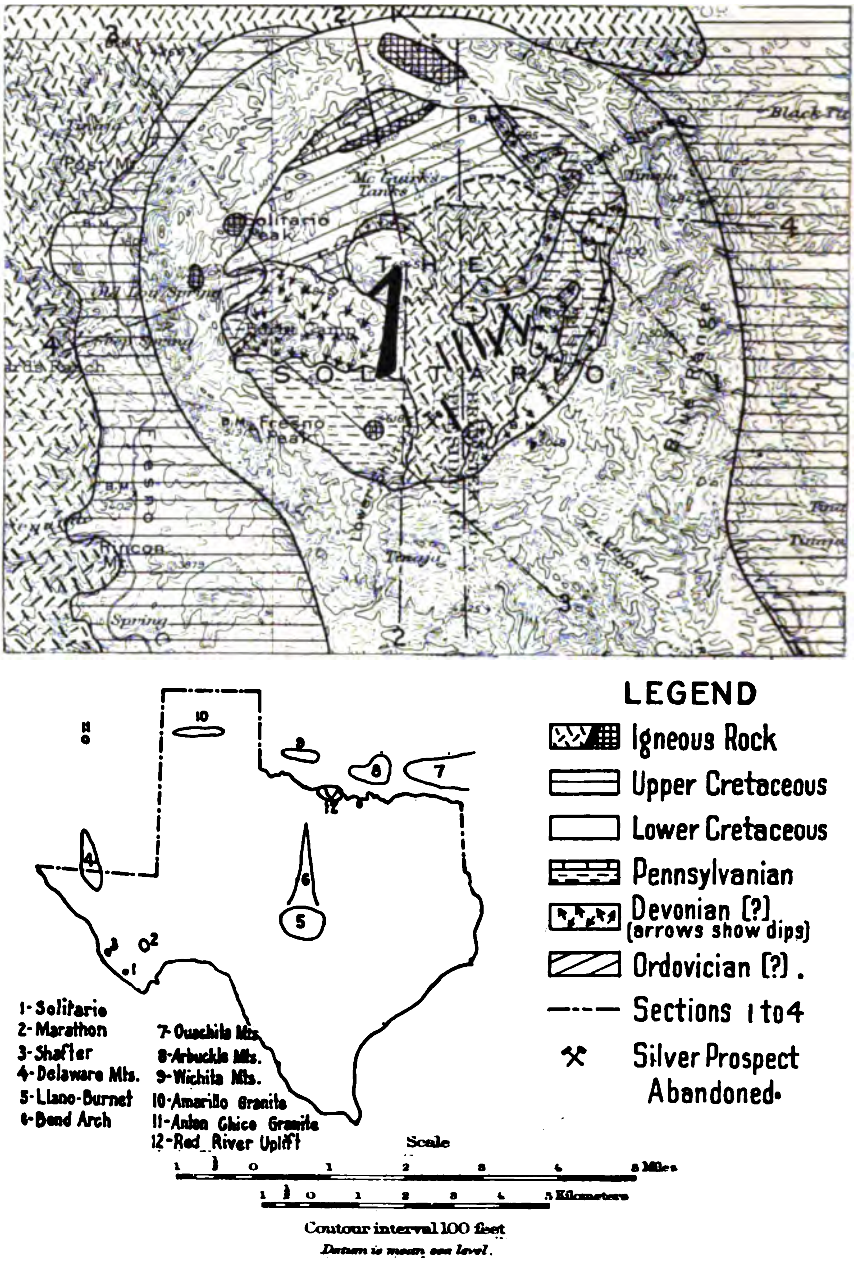

FIGURE 1.—*Geological Map of the Solitario Uplift, Presidio-Brewster Counties, Texas*

The accompanying outline map of Texas shows the relative position of the uplift to other areas of folding.

The most remarkably symmetrical dome attracted the attention of the writer in 1919, in passing, and caused him to spend several days within it in 1920 in part in the company of Wallace E. Pratt, to whom he is indebted for many suggestions. Mr. W. S. Adkins and others of the Bureau of Economic Geology, Austin, Texas, have studied the area in detail, under the direction of Dr. Udden, and the present brief description is preliminary to their report.

SUMMARY

Geologically, the Solitario consists of an unroofed, steep-sided, flat-topped dome formed of Lower Cretaceous limestones, within which there is an eccentric dome of steeply tilted Ordovician cherts, limestones, and shales, Devonian (?) novaculite, Pennsylvanian shales and sandstones, and Permian limestones. A portion of the Cretaceous cover is preserved in the center of the dome on a high ridge which runs from east to west. South of this ridge the Pennsylvanian shales and sandstones on the south side of the Ordovician dome are cut and in part covered or replaced by volcanic breccias and intrusives (figure 2). Volcanic activity is everywhere visible in dikes, sills, and laccoliths, the most extensive sill being within 20 to 100 feet of the base of the Cretaceous and extending around a great part of the periphery of the dome, as well as through the inlier in the center. Solitario Peak is an igneous mass, probably a volcanic plug, and an unnamed hill on the north is a laccolith, but no attempt is made to map or describe the other igneous masses.

The Solitario and the Marathon uplift, 60 miles northeast, are part of an area mountain-built in Permian time and later buried. The broad and gentle uplift of the latter after Cretaceous deposition is believed to have resulted from compression at right angles to the direction of the earlier forces. The very abrupt and symmetrical doming of the Solitario may be accounted for in the same manner or possibly by a laccolithic intrusion in basal Paleozoic strata. The Cretaceous cover of the Solitario

County, Texas, University of Texas, Bulletin 93, 1907; J. A. Udden, Notes on the geology of the Glass Mountains; and C. L. Baker and W. F. Bowman, Geologic exploration of the southeastern Front Range of trans-Pecos, Texas, University of Texas, Bulletin 1753, 1917; J. A. Udden, C. L. Baker, and E. Böse, Review of the geology of Texas, University of Texas, Bulletin 44, 1916; R. A. Liddle, The Marathon fold and its influence on petroleum accumulation, University of Texas, Bulletin 1847, 1918; B. F. Hill, The Terlingua quicksilver deposits, Brewster County, University of Texas, Bulletin 15, 1902; T. W. Vaughan, Reconnaissance in the Rio Grande coal fields of Texas, U. S. Geological Survey, Bulletin 164, 1900; J. A. Udden, The anticlinal theory as applied to some quicksilver deposits (Terlingua District, Brewster County), University of Texas, Bulletin 1822, 1918.

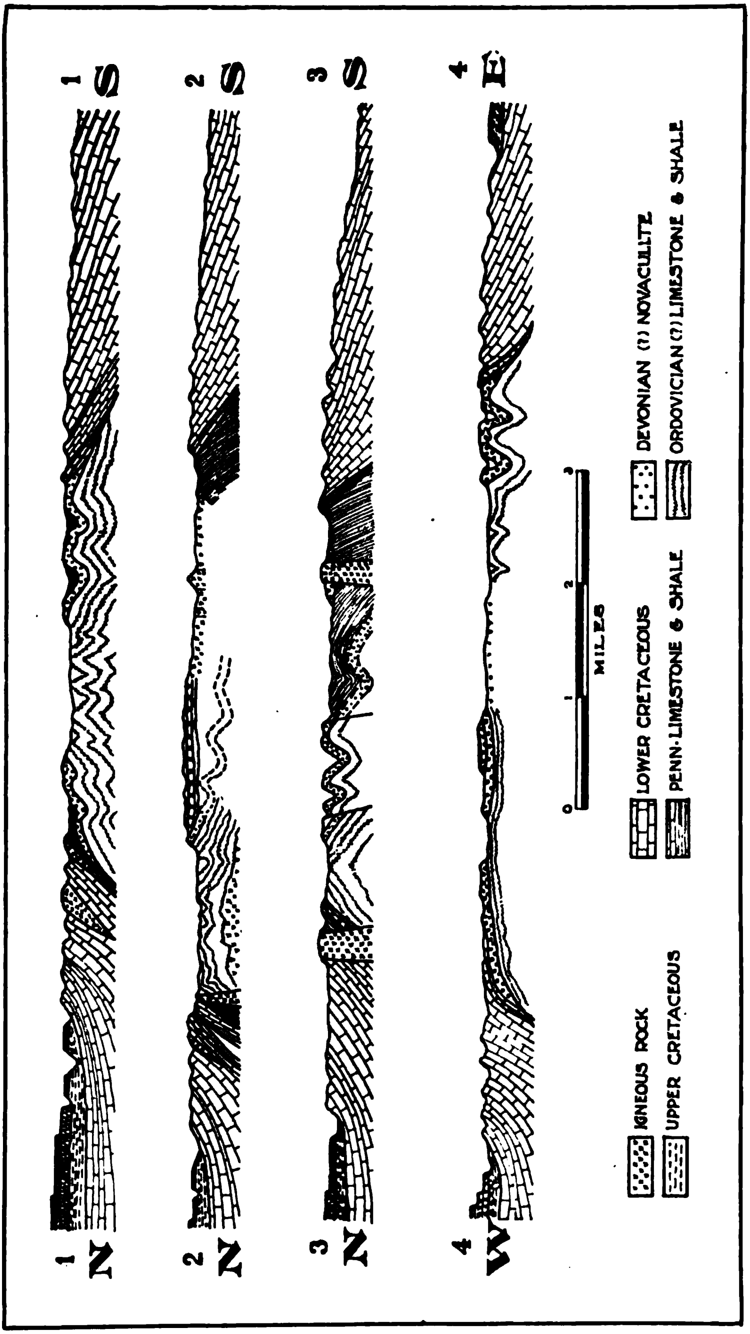

FIGURE 2.—*Cross-sections of the Solitario Uplift*

has been fractured by faults and by volcanic intrusions and extrusions and largely eroded.

Regional Geology

The Big Bend country and the area to the northward comprise the volcanic plateau of western Texas. A vast region is covered by lava flows and ash beds or by bolson deposits which conceal the bedrock. Cretaceous rocks are exposed at the edges of, and occasionally within, the volcanic area.

That volcanic activity began during the Upper Cretaceous and continued into the Tertiary is shown by plant remains.[3] The lavas are andesitic and rhyolitic in character and they are described by Dr. Whitman Cross in an unpublished manuscript of the United States Geological Survey by Mr. R. T. Hill on the Big Bend country. Both flows and ash beds can be traced for many miles in mesas, and the good exposures invite careful mapping and study.

Structure of the Big Bend region must be considered for the Paleozoic and Cretaceous terranes separately. The younger, as shown to the writer by Mr. Hill and later observed in the field, forms a high plateau 100 miles in width, broken on either side by fault blocks tilted toward the plateau.[4] The faults on the east are in the Boquillas (Carmen) Mountains; those on the west are in the Sierra Vieja Mountains. Many other faults with profound escarpments, like those south of Lajitas and Terlingua, add complexity to the structure. In spite of these fractures, the Rio Grande has maintained its course developed during the igneous activity, and the only sedimentary records of the canyon-cutting stage, as interpreted by the writer, are part of the very thick bolson deposits between Presidio and El Paso. In Mexico, the Burro Mountains southeast of the Big Bend represent block-faulted Cretaceous mountains cut by intrusions.

Paleozoic rocks outcrop at only four localities in the Big Bend region—Marathon, the Solitario, Shafter, and west of the Chinati Mountains, in Pinto Canyon (undescribed). The nearest Paleozoic areas are the Guadalupe and Delaware Mountains to the north (figure 1) and the Llano-Burnet (Central Mineral) region to the east. The former is

[3] E. W. Berry: An Eocene flora from trans-Pecos, Texas. U. S. Geol. Survey, Professional Paper 125A, 1919.

[4] C. L. Baker described this plateau as a block relatively less elevated than any other part of the trans-Pecos (Review of the Geology of Texas, University of Texas, Bulletin 44, 1916, p. 15).

clearly a part of the Cordilleran region. The latter is a block-fau uplift comparable to a horst, which shows very gentle folding. It fo the southern end of the Bend arch. The Paleozoic rocks in the Solit and Marathon areas show the same northeast-southwest strike, but continuation of this line of folding has not been traced beneath younger sediments. On the north side of the Marathon area the G Mountains, composed of a great thickness of Permian limestones, m locally, the southern limit of a series of Permian sediments unconfo able with the earlier Permian, which extend into New Mexico with abr lithologic change. Somewhere east of the truncated edges of these I mian sediments another Bend arch may be found extending toward Wichita Mountains. Buried granite knobs have been found to ext through Beckham County, Oklahoma; Amarillo, Texas, and Anton Ch New Mexico, and this evidence may be interpreted as indicating a l of connection between the Arbuckle and Wichita Mountains and the B arch-Marathon-Solitario folding. All this folding is, however, Ap lachian, as long ago pointed out by R. T. Hill,[5] because the Cordille folding began with the Laramie revolution.[6] Contrasting the Cretace Cordilleran and Paleozoic Appalachian structures, the strike of former is northwest-southeast, the latter at right angles. Undoubte the combination of these lines of folding has been an important, if no decisive, factor in the formation of domes such as the Solitario ε Marathon. The exposures of Pennsylvanian and Permian rocks Shafter and probably west of the Chinati Mountains are acciden because they are apparently the tilted edges of east-west fault blo exposed in the deep dissection of the volcanics by Cibolo Creek. Simi exposures in Mexico are reported to the writer by Dr. Udden.

Detailed Geology

STRATIGRAPHY

Fossils in pre-Cretaceous rocks are difficult to find, and the age de minations are made by analogy with the Marathon region, where excell

[5] Physical geography of the Texas region. U. S. Geol. Survey, topographic atla the United States, Folio 3, 1900, p. 4.

[6] Willis T. Lee disagrees with this reasoning in his paper on "Granite in eastern Mexico wells" (Bull. Amer. Assn. Pet. Geol., vol. 5, no. 2, 1921, p. 165), where he sta "The Pennsylvanian sedimentation was brought to a close in New Mexico by the el tion of mountains which the writer has termed the Ancestral Rocky Mountains. Pennsylvanian strata were upturned in these mountains, eroded, and probably in ε places entirely removed. . . . It seems appropriate to regard [the post-Pennsylva unconformity] as a major unconformity."

collections have been made. Cambrian fossils have been identified in an anticlinal fold south of Marathon, but not at the Solitario. The white novaculite, which forms conspicuous ridges in the northern half of the uplift, is the most conspicuous Paleozoic formation, and it is clearly the Caballos novaculite which is possibly of Lower Devonian age. Beneath it and within the novaculite rim in the northern half are the black cherts and silicified shales, which belong to the Maravillas formation of Middle and Upper Ordovician age and contain graptolites at Marathon.[7] The older blue and gray limestone and black shale are probably the Marathon formation of Lower and Middle Ordovician age. Overlying the novaculite and structurally conformable with it is the Tesnus formation, of Pennsylvanian age.[8] The Tesnus formation is exposed in the south part of the Solitario and in the synclines in the northeast and southwest parts of the novaculite. Plant remains collected 225 feet from the top of the Tesnus formation at Marathon (latitude, 30° 5½′; longitude, 103° 19′) were identified by Mr. David White as probably of Upper Pottsville age, to be correlated with the base of the Magdalena group of New Mexico and with either the Strawn or Bend formations of west central Texas. Uplift and erosion everywhere followed the deposition of these and accompanying formations.

Pennsylvanian or Permian (?) limestones are exposed on either side of the wagon road in the north end of the Solitario, between the basal Cretaceous conglomerate and hills of igneous rock. The hills seem to represent an intrusion which came up along the fault separating these limestones from those of Ordovician age. The limestone is bright yellow in color, the appearance being similar to that of the Permian limestone in Shackelford County. It contains crinoids and other poorly preserved fossils, which are of Upper Paleozoic age. The only Pennsylvanian limestone with which it can be correlated is the Dimple at Marathon, but there are many Permian limestones.

Lower Cretaceous sedimentation followed a period of orogeny and erosion. The basal Trinity conglomerate, 100 feet or more in thickness, consists of well rounded pebbles. The absence of lithologic breaks in the overlying limestone series and the thinness of the basal conglomerate

[7] Dr. Rudolf Ruedemann identified the graptolites as of Trenton Normanskill age. Collections from the Viola limestone in the Criner Hills, Oklahoma, indicate a slightly younger Trenton horizon.

[8] This formation was measured along San Francisco Creek parallel to the Southern Pacific Railroad east of Marathon and found to be 7,590 feet thick, subject to duplications, but only two, apparently minor faults, were observed. Baker and Bowman measured the thickness as 3,370 feet. The overlying Dimple formation was determined to be 882 feet thick.

FIGURE 3.—*Panoramic Views of the Exterior of Solitario Uplift*

The upper picture shows the rim of Lower Cretaceous limestone as seen from the southwest. The lower picture shows the Lower Cretaceous mountains on the left, the Upper Cretaceous hills in the foreground, and the lava-capped mesas on the right.

indicate rapid subsidence of the region and relatively great distance from a shore.

Most remarkable exposures of Lower Cretaceous limestone form the rim of the Solitario one mile in width on the north, east, and west sides, dipping 30 degrees to 50 degrees (figure 3). More gentle dips on the southeast extend these limestones 5 miles from the rim. The thickness of the limestone must be over 3,000 feet. Above it and in the valleys surrounding the rim the Del Rio clay and the Buda limestone may both be recognized as at Del Rio. The latter is, in places, very white.

Upper Cretaceous sediments, except the Eagle Ford flags, are lacking. These flags consist of bluish arenaceous shale and of sandstone, which weather dark yellow in color. They compose the low hills on the outer side of the circular drainage system and they also compose the low hills south and southwest of the dome, where they become chalky.

Lava flows and ash beds capping the volcanic plateau overlie the Eagle Ford flags, but the folding in the latter is so gentle that the structural relations with the flows were not observed. Elsewhere the Austin chalk and Taylor marl or their equivalents have been found in western Texas, but it is doubtful if they were ever deposited here. Uplift and volcanic activity began after the Eagle Ford sedimentation.

STRUCTURE

The structure of the Solitario is shown in the cross-sections presented in figure 2. The Paleozoic rocks are closely compressed with folds, some of which are isoclinal or even overturned. These folds are best seen in the hills on the east and west—on the east where a creek cuts through the novaculite and winds between two anticlines of novaculite, and on the west in the novaculite ridges which finger out toward Burnt Camp into anticlines which disappear beneath the Cretaceous. Another outcrop of novaculite south of McGuirk's tanks is overlain by Cretaceous limestone.

When the outcrops of novaculite are considered together, the continuous and curved ridge on the east shows a pronounced dip outward from the central plain; the ridge on the south shows tilting to the south and the ridge on the west also shows a southern dip. On this evidence the plain which forms the northern half of the uplift is believed to be anticlinorial, and the novaculite, which would normally outcrop in parts of this area, is believed to have been eroded from an older arch in pre-Cretaceous time.

Subtracting the dips of the Cretaceous rocks from those of the Paleo-

zoic strata gives approximately the dips of the older series in pre-Cretaceous time, except for the foreshortening taken up in metamorphism. Therefore the dips must have been 5 degrees to 50 degrees. At Marathon the Cretaceous now dips at angles of 3 degrees to 10 degrees over truncated folds which are in part isoclinal. This relation indicates that the major folding in the Big Bend region was pre-Cretaceous.

The Cretaceous rocks are more gently and regularly folded on the sides of the uplift, the steepest dips being on the north, northeast, and west. The eroded edges of these limestones at the basal contact with the older rocks around the periphery of the dome dip steeply, but on the western side the contact is still preserved, extending within the dome and rising to the top of a ridge of novaculite. Here the degree of dip in the limestone diminishes rapidly and becomes gentle and almost flat above the novaculite. This relation suggests that a relatively flat arch of limestone existed over the uplift before the dome was disrupted by igneous intrusion accompanied by faulting. It further suggests that the post-Cretaceous doming can be compared with the punching upward of a circular core by igneous intrusion.

Inliers of Cretaceous limestone cap several hills in the volcanic area at the south end of the uplift. Still other fragments of limestone are found in the volcanic breccia, into which they have evidently fallen with the erupted material. The volcanic disturbances have depressed the inliers below the base of the limestone in the Solitario rim.

The principal inlier is in the center of the dome. The central hills consist of Cretaceous limestone with a sill at the base resting on novaculite and cut off or overlain by volcanic breccias on the east and south. A dike separates the limestone from the novaculite on the west. The elevation of the base of the limestone on the north is approximately the same as that of the basal contact around the dome, but the dip of the inlier is to the south. Such relationship may be explained in at least two ways: The folding in the limestone roof may originally have conformed to relative competence of formations accentuated by folding and the inlier may be part of an original syncline. On the other hand, this inlier more probably owes its present position to faulting.

Origin

The problem is to explain the origin of a circular, flat-topped dome 5 miles in inside and 8 miles in outside diameter, uplifted one mile in a horizontal distance of 2 miles. The Marathon dome is broad, with gentle

slopes. It has a diameter of approximately 36 miles, with an uplift of about one mile in 10 miles or more. In both areas there were two periods of major folding, with compressive forces of the second period acting at right angles to those of the first period. At the Solitario there was intense volcanic action manifested as intrusives and extrusives, while at Marathon there was practically no volcanic action.

Intrusion of a laccolith or other igneous body into the lowest Paleozoic strata at the Solitario may explain the abruptness of the uplift. The sills, dikes, and volcanic breccia would be connected with such a body. Six or more laccoliths in and near the Chisos Mountains southeast of the Solitario have been described by Dr. Udden.[9] The Christmas Mountains, near by, are a faulted dome in Cretaceous limestone, one and one-half miles in diameter, uplifted 3,500 feet, and are probably a laccolith, as yet unroofed. Other similar intrusive uplifts are found farther south in the Burro Mountains of Mexico.

This hypothesis would explain the circular outline, the steep sides, and apparently flat top of the dome. Furthermore, some intrusive body or bodies must underlie the dome, because of the concentration of dikes, plugs, and sills and because of the vast amount of volcanic breccia which has come from some intrusive which broke through to the surface. It is, however, difficult to conceive of the form and size of an intrusive, even of an intraformational laccolith, in complexly folded rocks which would fulfill the requirements. The laccolithic intrusions above cited seem to be confined to Cretaceous limestones.

Another hypothesis is that the doming can be explained by tectonic forces without igneous intrusion. An analogous uplift in Tennessee has been called to the attention of the writer by W. A. Nelson, the State Geologist. This dome, the Wells Creek Basin, in Stewart County, near Cumberland City, is two miles in outside diameter and shows an uplift of about one-half mile, with dips around the edges "at high angles and at some points even vertical."[10] This uplift of Upper Cambrian into Mississippian limestone is 70 miles from the nearest dike in Kentucky. An unconformity is shown in the section at the dome, but not elsewhere, and therefore the dome is a rejuvenation of an older uplift. The doming is clearly the result of tectonic movements free from igneous action.

[9] University of Texas, Bulletin 93, 1907; 1753, 1917, p. 148. Also, U. S. Geol. Survey, topographic atlas, Chisos Mountains quadrangle.

[10] J. M. Safford: Geology of Tennessee, 1869, p. 147, par. 364-5.

J. J. Galloway: Geology of natural resources of Rutherford County, Tennessee, Geological Survey of Tennessee, Bulletin 22, 1919.

From the analogy of the Wells Creek Basin it is believed that the original doming of the Solitario was caused principally by tectonic forces. It is further believed that the symmetry of the dome is related to the preexisting structure in the older rocks, which was probably anticlinorial, this structure forming a locus for the concentration of stresses developed during the folding of the Cretaceous rocks.

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INCREASED OCEANIC SALINITY AS ONE CAUSE OF INCREASED CLIMATIC CONTRASTS[1]

BY STEPHEN SARGENT VISHER[2]

(*Presented before the Society December 28, 1920*)

CONTENTS

INTRODUCTION

One of the great problems of geology is the explanation of the differences between the climate of the present and that of the past. Today there are great contrasts from zone to zone and from season to season. During much of the past there was relative uniformity from latitude to latitude and from summer to winter. Doubtless many factors helped bring about this change. One factor that appears not to have been discussed, however, is increased salinity of the ocean. There is a general agreement among geologists that the ocean has become increasingly saline throughout the ages. Indeed, calculations of the rate of accumulation of salt have been a favorite method of arriving at estimates of the age of the ocean and hence of the earliest marine sediments. So far as known, however, no geologist or climatologist has discussed the probable climatic effects of increased salinity. Yet it seems clear that an increase in salinity must have a slight effect on climate, and may possibly help to explain some of the puzzling facts of earth history.

SALINITY DECREASES EVAPORATION

The change from a slight salinity, when the ocean was young, to the

[1] Manuscript received by the Secretary of the Society July 6, 1921.
[2] Introduced by Ellsworth Huntington.

present salinity of 3.5 per cent would help produce zonal and seasonal extremes chiefly in three ways:

Increased salinity reduces the rate of evaporation. According to the experiments of Mazelle and Okada, as reported by Krümmel, evaporation from ordinary sea-water takes place from 9 to 30 per cent less rapidly than from fresh water, under similar conditions. (The difference in the percental effect of salinity depends largely on whether the water is stirred by winds or not.) Hence increased salinity during geologic time has reduced evaporation, and thus, doubtless, has lessened the amount of water vapor in the air. The water vapor in the air is the chief blanketing agent. Reduction in the blanketing effect of the atmosphere means more severe diurnal and seasonal range of temperature and greater contrast from zone to zone.

Salinity lowers the freezing Point

Increased salinity also means a lower freezing temperature of the ocean. The present salinity of about 3.5 per cent lowers the freezing point of the ocean from 32 degrees Fahrenheit almost to 28 degrees Fahrenheit. If the ocean were fresh and our winters as cold as now, all the harbors of New England and the Middle Atlantic States frequently would be icebound. The North Sea would also be frozen frequently and the British Isles occasionally locked in ice, and in subpolar latitudes the area of permanently frozen oceans would be much enlarged. The indirect effects of the lower freezing point of saline than of fresh water are even more significant than the direct effects.

One direct effect of the low freezing point of saline water is that the open ocean in high latitudes is now cooled below 32 degrees Fahrenheit in winter. Indeed, the temperature of the entire ocean is probably distinctly lower now than it would be if the ocean were less saline. This is because an unfrozen sea loses its heat to the air fairly rapidly, while one covered with widespread ice-floes in high latitudes loses heat much more slowly, for ice is an excellent non-conductor of heat. If the ocean were much fresher than now and the climate as cold, ice-floes would be much more widespread than now. Widespread climatic consequences seemingly result from the lower ocean temperature induced by the free radiation of heat from the open water to the cold air above. Since a liquid's capacity for holding gas in solution varies inversely as the temperature, the ocean is able to absorb and hold considerably more atmospheric CO_2 now than it could if it were not so cold. Certain data suggest that if the ocean were warmed to an average of only 2 degrees Fahrenheit above its present

temperature, its capacity for holding CO_2 in solution would be sufficiently reduced so that it would give up enough of its abundant supplies of this gas to the air to double the present atmospheric amount. The climatic significance of atmospheric CO_2, while probably not as great as some have thought likely, nevertheless certainly is appreciable. Even Humphreys[3] admits that a doubling or halving of the CO_2 content of the air would produce directly a temperature change of about one-fifth of that estimated to have occurred since the height of glaciation. The indirect effects of changed CO_2 content of the air are certainly greater than the direct.

A second indirect effect of the lower freezing point produced by increased salinity also springs from the fact that less of the sea is ice-covered, but it depends on the effect of the ice on air temperatures instead of on water temperatures. When the sea is ice-covered it gives up practically no heat to the air and becomes, to all intents and purposes, a land surface. As a result, continents bordered by an ice-covered sea become much colder in winter than lands bordered by an open sea. This is due not only to their receiving less heat, but because they lose far more quickly whatever heat they may have left from the supply received from the sun the preceding autumn. When the wind blows from an open ocean in winter it causes a fog and clouds on the adjacent lands, and these hold in the heat. If a coast is ice-bound, the belt of fog and cloud is pushed seaward, and the cloudiness on the continent diminishes and the heat is radiated away far more quickly than when the sky is cloud-covered. With decreased cloudiness, snowfall would decrease on the lands. The summers of the Arctic Ocean are now kept exceptionally cold by the snow-mantled ice, with its great reflection of sunlight and its large absorption of heat in melting.

Furthermore, because of the low temperatures, anticyclonic conditions prevail, with the result that the winds usually blow radially outward from the ice-covered portions.[4] When the oceans were fresher than now, this effect must have been magnified, with a consequent diminution of polar and subpolar snowfall in summer as well as winter. This means that under given conditions of temperature, land distribution, and so forth, the ice-covered portion of the ocean was greater, and hence the possibilities of precipitation at high latitudes were less with the less

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[3] W. J. Humphreys: Physics of the air, 1920, p. 607.

[4] C. E. P. Brooks: The meteorological conditions of an ice-sheet and their bearing on the desiccation of the globe. Quart. Journ. Royal Meteorol. Soc., vol. xl, 1914, pp. 53-70.

W. H. Hobbs: Characteristics of existing glaciers, 1911. The rôle of the glacial anticyclone in the air circulation of the globe. Proc. Am. Phil. Soc., vol. liv, 1915, pp. 185-225.

saline seas of the past than at present. This condition, coupled with the fact that evaporation, a cooling operation, is favored by the absence of salt, may have been one reason why, when for some reason it was cold enough on the earth for glaciers to be widespread, the glaciated areas of the earlier ice ages, such as the Proterozoic and Permian, were located farther south than were the ice-sheets of the recent Glacial period. If the ocean were ice-covered down to middle latitudes, a lack of glaciation in high latitudes would not be any more surprising or harder to explain than is the lack of Pleistocene glaciation in the northern parts of Alaska and Asia. In both cases the coldness of the ice-sheet of lower latitudes apparently induced prompt condensation of the wind-borne moisture. Hence not enough moisture was carried into higher latitudes to produce glaciers there.

It is not known how saline the ocean was at any given time in the past, but the fact that salt deposits are lacking in the rock formations before the Paleozoic, according to Barrell,[5] suggests that in the Proterozoic it was decidedly less than now. Schuchert surmises that the salinity of the Proterozoic was perhaps 1 per cent instead of the present 3.5 per cent.

Salinity affects the Rate of deep-sea Circulation

The third great effect of the lower salinity of the past than at present is on the deep-sea circulation of the ocean. The vertical circulation is now dominated by cold water from subpolar latitudes. All but the surface of the ocean is almost freezing cold, because cold water sinks in high latitudes by reason of its greater density, due to its low temperature. It then "creeps" to low latitudes, where it rises and replaces either the water moved poleward by surface currents produced by the trade winds or that which has evaporated from the surface. During past ages, when the sea-water was less salty than at present, the circulation was presumably more rapid than now. This is because in tropical regions the rise of cold water is interfered with by the sinking of warm surface water, which is relatively dense because evaporation has removed part of the water and caused an accumulation of salt.

According to Krümmel and Mill,[6] the surface salinity of the subtropical belt of the North Atlantic commonly exceeds 3.7 per cent and sometimes reaches 3.77 per cent, whereas the underlying waters have a salinity of less than 3.5 per cent and locally as little as 3.44 per cent. The other oceans are slightly less saline than the North Atlantic at all depths, so

[5] J. Barrell: The origin of the earth, in Lull and others: The evolution of the earth and its inhabitants, 1918, p. 32.

[6] The ocean. Encyclopedia Britannica, 11th edition.

the vertical gradients along the tropics are similar. According to the "Smithsonian Physical Tables," the observed difference in salinity of surface and underlying water is equivalent to a difference of .003 in density, where the density of fresh water is taken as 1.000.

Since the decrease in density produced by warming water from the temperature of its greatest density (4 degrees centigrade) to the highest temperatures which ever prevail in the ocean (30 degrees centigrade or 86 degrees Fahrenheit) is only .004, it is evident that the more saline surface waters of the dry tropics now are only a trifle less dense than the less saline but colder waters beneath the surface. During the days of especially great evaporation the most saline portions of the surface waters in the dry tropics are denser than the underlying waters, and therefore sink and produce a temporary local stagnation in the general circulation. Such a sinking of the warm surface waters is reported by Krümmel as observable by the sudden rise of temperature it produces at considerable depths. If such a hindrance to the circulation did not exist, the velocity of the deep-sea movements certainly would be greater than at present.

If in earlier times such more rapid circulation occurred, low latitudes were cooled more than now by the rise of cold waters, and at the same time high latitudes were warmed by a greater flow of warm water from tropical regions. In that case there was less contrast in climate between the different latitudes. Hence, in so far as the rate of the deep-sea circulation depends on salinity, there apparently has been an increase in the contrasts from latitude to latitude. Thus increased salinity during geologic history helps a little to explain the well established fact that during most of the past the climatic contrast between tropical and subpolar latitudes has been less than at present.

Though the process of adding salts to the ocean has presumably gone on at all time, two sorts of conditions may have temporarily hastened it, and thus intensified whatever slight climatic effect increased salinity may have produced. At times of continental glaciation, the average salinity of the ocean is increased to the extent that the ocean level is lowered to supply the water necessary to form the glaciers. It has been calculated that the accumulation of the Pleistocene ice-caps lowered the ocean more than 200 feet; perhaps as much as 300 feet. The salts in this amount of water would be added to the remaining ocean water and would increase its salinity by about 2 per cent (from 3.5 per cent to 3.57 per cent), and to that extent would tend to slow up the deep-sea circulation.

An emergence of the continents would be accompanied by rapid erosion, by a lowering of the level of ground-water, and by the transfer to the ocean of part of the vast quantities of salt and other soluble mineral

matter which had accumulated in the soil and subsoil on the lands when they were only slightly above sealevel. If widespread glaciation should accompany or follow extensive uplift, as it did in the Proterozoic, Permian, and Pleistocene, the rate at which salts were added to the ocean would be increased by both these agencies at about the same time. While uplift and glaciation were increasing the amount of mineral matter brought to the ocean in solution by the rivers, the rate of withdrawal of mineral matter from solution would probably be lessened. At present the calcareous and siliceous materials, which form a large part of the mineral matter carried to the sea by the rivers, but only a minor part of what is generally called the salines of the ocean, are rather promptly removed from solution, perhaps chiefly through the activity of the marine animals and plants, which use these minerals for their shells and supports.

Restriction of the area of the continental shelf accompanying continental emergence and the accumulation of extensive ice-caps would doubtless greatly reduce the number and average size of shell-secreting marine organisms, for most of them live in shallow water, on the continental shelf. Furthermore, the lower coastal temperatures accompanying glaciation would probably make the remaining animals less active in shell formation. If so, lessened withdrawal of salts would cooperate with an increased supply to cause the salinity of the ocean to increase rapidly during glacial periods.

Possibilities of a reversal in Direction of the deep-sea Circulation

Under the conditions set forth in the preceding paragraph, and perhaps under certain others, the salinity of the ocean as a whole, or of its warmer portions, may have been temporarily greater than now, and thus the more saline warm water of the dry tropics would become more dense than the colder but less saline waters of subpolar latitudes. If so, the reversal in direction of the deep-sea circulation suggested by Chamberlin[7] may have occurred. One result of such a reversal would be that lands in the higher latitudes would be warmed much more effectively by winds blowing from the sea than before the reversal took place. If such a reversal was brought about by the consequences of uplift and glaciation, described in the foregoing paragraph, conditions for continued glaciation would seemingly be made less favorable. Indeed, a reversal might bring the glaciation to a close.

[7] T. C. Chamberlin: On a possible reversal of the deep-sea circulation. Jour. of Geology, vol. 14, 1906, pp. 363-373.

As one of the particularly interesting problems connected with glaciation is the question as to what agency or agencies brought the several Glacial epochs to a close, it is worth while to consider briefly the data bearing on the question of reversal of deep-sea circulation. Such a reversal may never have occurred, and it is at least very doubtful if it was the chief cause for the retreat of the glaciers. However, the possibilities should not be ignored. The close balance between the forces maintaining the present type of circulation and those tending to produce a reversal is therefore worth pointing out.

At present the average salinity of the ocean is 3.5 per cent, giving a density of about 1.026, fresh water being 1.000. The most saline samples of the open ocean taken by the Challenger Expedition had a salinity of 3.74 per cent, giving a density of about 1.028. The somewhat less salty surface waters of the open ocean in high latitudes are reported to have a density of 1.024. Thus the observed range in density due to salinity is .004 in favor of the tropics. A change in temperature from 4 degrees centigrade, the temperature of greatest density of fresh water, to 30 degrees centigrade (86 degrees Fahrenheit) produces a change of density of exactly the same amount, .004, according to the "Smithsonian Physical Tables." Hence the most extreme cooling now experienced has no more influence on density than the observed difference in density due to salinity.

If the contrast in density between low and high latitudes were increased slightly, the tropical waters would become distinctly more dense than the most dense subpolar waters, and hence a reversal would be probable. Such an increased contrast might result either if tropical waters were more dense than now, as they would be if the average salinity were increased, or if the rate of tropical evaporation were increased. It would also result if the subpolar surface waters were less dense than now, as they would be if subpolar regions were not so cold as now or if there were more precipitation in high latitudes.

The probable increased steadiness and strength of the southwesterly winds, suggested by Huntington[8] as probable during times when cyclonic storms are few, would have warmed high latitudes and would also have reduced evaporation, thereby increasing fogginess and cloudiness. Precipitation would probably increase with cloudiness and fog.

If at any time in the past the deep-sea circulation was of the reversed type during a long period, the presence of magnolias, cycads, and sequoia found fossilized in northern Greenland in Miocene rocks, the tree-ferns

[8] Ellsworth Huntington: Climatic changes (in press).

and breadfruit found in western Greenland, and several other puzzling questions of paleoclimatology would be easily explained, for such a deep-sea circulation would mean that vast quantities of tropical warmth would be transferred to high latitudes beneath the surface without loss en route.

However, there is no direct evidence that an actual reversal has ever taken place. Indeed, Chamberlin, who first suggested the possibility of a reversal, offered it merely as an interesting possibility. Nevertheless, a change in the salinity of the oceans must apparently have had some distinct effects. Though these may have been small, they are not to be neglected in any complete study of the climate of the past.

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SWEET GRASS HILLS, MONTANA[1]

BY JAMES F. KEMP AND PAUL BILLINGSLEY

(Presented before the Society by the senior author December 31, 1919)

CONTENTS

INTRODUCTION

The Sweet Grass Hills are a group of three separate laccolithic centers in the northern part of Toole County, Montana, and almost touching the

[1] Manuscript received by the Secretary of the Society August 22, 1921.

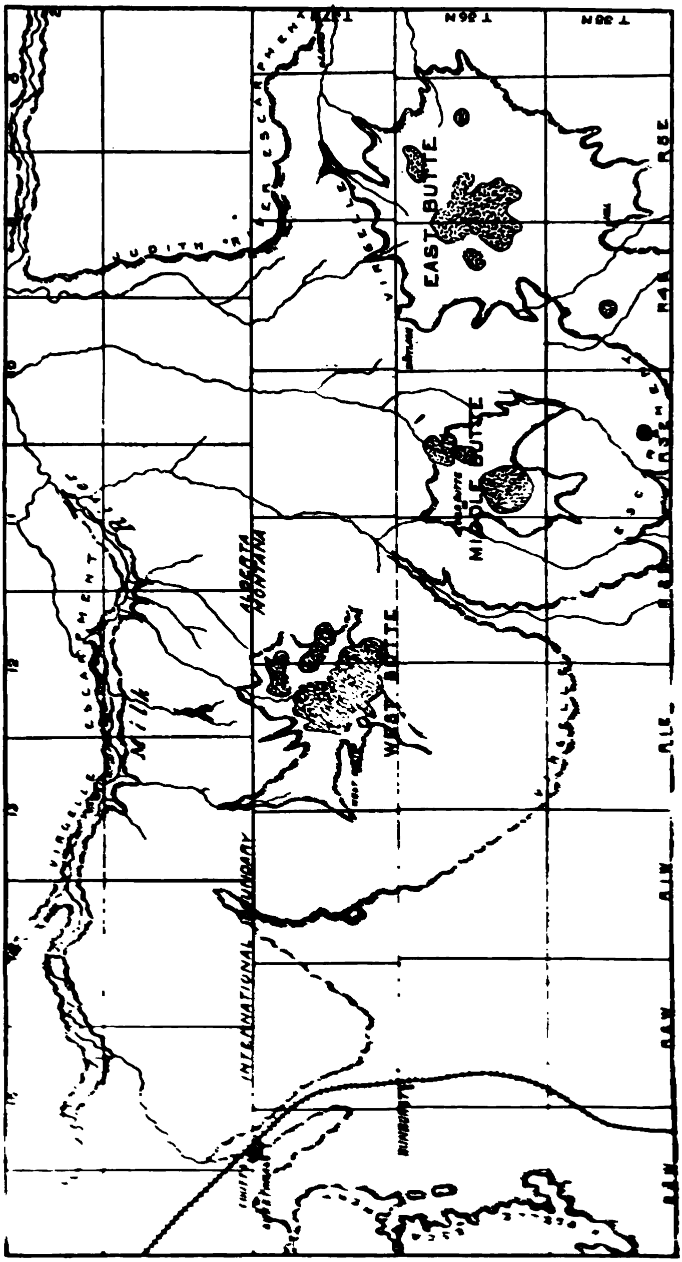

Figure 1. Map of the Sweet Grass Hills, Montana

international boundary. All three rise abruptly from the plains at a distance of approximately 100 miles east of the Rocky Mountains. The summits at the maximum are nearly 3,000 feet above the neighboring plains and are striking landmarks, even when viewed from the railway train at a distance of 40 or 50 miles. As a result of observations made in 1873-74, Dr. George M. Dawson[2] records that these isolated mountains were called by the half-breed hunters "Montagnes du Foin de Senteur," and by the traders of the Missouri region the "Sweet Grass Hills." On the maps of that time they were also named "Three Buttes." Today the name Sweet Grass Hills seems well established and in general usage.

The three elevations are called, from east to west, East Butte, Middle Butte, and West Butte. The center of the Middle Butte uplift is distant 10 miles from the center of West Butte and practically the same from the center of East Butte. The area of uplift for East Butte is, roughly, 9 miles from east to west and 10 miles from north to south. Middle Butte is smaller. Its uplift extends about 5 miles from east to west and the same distance from north to south. West Butte covers an area, roughly, 5 miles east and west by 6 miles north and south. The relative positions are shown on figure 1. West Butte is some 20 miles east from the town of Sweet Grass, on the branch of the Great Northern Railroad, which connects the main line with the Canadian railway leading north into Alberta. The town is at the international boundary. The main line of the Great Northern is somewhat farther south of the hills. A mail auto-service runs daily from the post-office of Gold Butte, on the western side of Middle Butte, southeast 28 miles, to Chester, on the main line of the Great Northern. As stated above, the Rocky Mountains are, roughly, 100 miles to the west. The Bear Paw Mountains, an eroded volcanic center, are nearly 100 miles southeast. To the south the Highwoods, embracing both volcanic plugs and laccoliths near Great Falls, are over 130 miles distant. To the north, in Alberta, there are moderate elevations of sedimentary strata in the Evergreen Hills, which can be seen from the Sweet Grass Hills on the farthest horizon. In the great plains there are no more outbreaks of igneous rocks to the north and east for hundreds of miles.

The Sweet Grass Hills are thus the most northerly of the laccolithic and volcanic mountains lying east of the main range of the Rocky Mountains in Montana, and of which the very valuable papers of Waldemar

[2] British North American Boundary Commission. Report on the geology and resources of the region in the vicinity of the forty-ninth parallel. Montreal, 1875, p. 123.

Lindgren,[3] J. E. Wolff,[4] W. H. Weed, and L. V. Pirsson[5] have furnished descriptions. The numerous contributions of Weed and Pirsson to our knowledge of these eruptive centers in the great plains constitute one of the most striking series of investigations in both structural geology and petrology which have appeared in recent years. The Sweet Grass Hills were not described by them, although a short contribution was made based on the early notes of Dr. George M. Dawson and on two specimens of rocks from East Butte, two from West Butte, and one from an outlying dike, all loaned by Dr. Dawson. The geographical relations of all the eruptive centers mentioned above are shown on figure 7, pages 464, 465.

Review of earlier Work

Investigations of George M. Dawson

We owe to Dr. George M. Dawson the principal records hitherto made on the geology of the Sweet Grass Hills. In connection with the International Boundary Survey, carried on in 1873 and 1874, he visited the

[3] Waldemar Lindgren: On some eruptive rocks collected by the Northern Transcontinental Survey. Tenth Census Repts., vol. 15, 1886, pp. 719-737. Proc. California Acad. Sci., Ser. II, vol. 3, pp. 39-57.

———: A sodalite-syenite and other rocks from Montana, with analyses by W. H. Melville. Am. Jour. Sci., April, 1893, pp. 286-297.

[4] J. E. Wolff: Geology of the Crazy Mountains, Montana. Bull. Geol. Soc. Am., vol. 3, 1892, pp. 445-452.

[5] W. H. Weed and L. V. Pirsson: Highwood Mountains of Montana. Bull. Geol. Soc. Am., vol. 6, 1895, pp. 389-422.

———: On the igneous rocks of the Sweet Grass Hills, Montana. Am. Jour. Sci., October, 1895, pp. 309-313.

———: Igneous rocks of Yogo Peak, Montana. Am. Jour. Sci., December, 1895, pp. 467-479.

———: Geology of the Castle Mountain mining district, Montana. Bull. U. S. Geol. Survey, 1896, p. 139.

———: The Bearpaw Mountains, Montana. Am. Jour. Sci., April, 1896, pp. 283-301; May, 1896, pp. 351-362; August, 1896, pp. 136-148; September, 1896, pp. 188-199.

———: Geology of the Little Rocky Mountains, Montana. Jour. Geol., vol. 4, 1896, pp. 399-428.

———: Missourite, a new leucite rock from the Highwood Mountains. Am. Jour. Sci., November, 1896, pp. 315-323.

———: Geology and mineral resources of the Judith Mountains of Montana. U. S. Geol. Survey, 18th Ann. Rept., pt. iii, 1898, pp. 446-616.

———: Geology of the Little Belt Mountains, Montana. U. S. Geol. Survey, 20th Ann. Rept., pt. iii, 1900, pp. 271-461.

———: Geology of the Shonkin Sag and Palisade Butte laccoliths, in the Highwood Mountains of Montana. Am. Jour. Sci., July, 1901, pp. 1-17.

W. H. Weed: Fort Benton Folio, U. S. Geol. Survey, no. 55, 1899.

———: Little Belt Folio, idem, no. 56, 1899.

L. V. Pirsson: Complementary rocks and radial dikes. Am. Jour. Sci., August, 1895, pp. 116-121.

———: On the monchiquites or analcite group of igneous rocks. Jour. of Geology, vol. 4, 1896, pp. 679-690.

———: On the corundum-bearing rocks from Yogo Gulch, Montana. Am. Jour. Sci., May, 1897, pp. 421-423.

buttes when there was still some danger from raiding parties of Indians. Dr. Dawson ascended both East and West buttes, collected specimens of the igneous rocks, and made valuable notes on the associated sedimentary strata. He noted the upheaval of the sediments, their quaquaversal dips from the intrusive centers, and described the features of the later named laccolites or laccoliths, without constituting them into a new and distinctive type.

The introduction of the term laccolite remained for G. K. Gilbert in 1877. The new name afforded an indispensable one for descriptive geology. Dr. Dawson likened the Sweet Grass upheavals to von Buch's "craters of elevation." The term is not a specially happy one, in that we associate craters with volcanoes, and there are no effusive rocks whatever in the Sweet Grass Hills. They are purely laccoliths, sills and dikes, and uptilted sediments.

RESEARCHES OF FRANK D. ADAMS, W. H. WEED, AND L. V. PIRSSON

Dr. Dawson made another hasty visit to West Butte in the years 1882-84, during his studies of the region of the Bow and Belly rivers. In connection with his report, published in 1884,[6] Frank D. Adams contributed some microscopic determinations of the principal igneous rocks, recognizing them as intermediate or transitional between trachytes and andesites—a general character which we have no reason to modify today, although, on account of their intrusive nature and to be in accord with the usage of Weed and Pirsson, we may speak of the same types as syenite porphyry and diorite porphyry.

The more complete and detailed collections of the writers have somewhat extended the acidic and basic limits and have brought to light some types rich in soda, such as also appear in the intrusive centers studied elsewhere by Weed and Pirsson.

Besides the commoner run of the rocks, Dr. Dawson collected specimens from a peculiar basic dike standing out like a wall in the plains 10 miles north of East Butte. It is very rich in biotite and was referred by him to von Cotta's kersanton. In the later paper by Weed and Pirsson this is more accurately described as minette. We have found the rock both in sills and dikes in a number of places. With the help of George M. Fowler, geologist on the staff of the Anaconda Copper Company, we have identified several localities of tinguaites and more acidic ægirite-bearing rocks in East Butte.[7]

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[6] Geological Survey of Canada. Report for 1882-1884, pp. 16C-18C, 45C-48C. 1885.

[7] The data for this paper were obtained in the following way: The two writers spent a week in the Hills in May, 1918, in company with George M. Fowler, who was in charge of some local explorations. The previous fall the junior writer had essentially

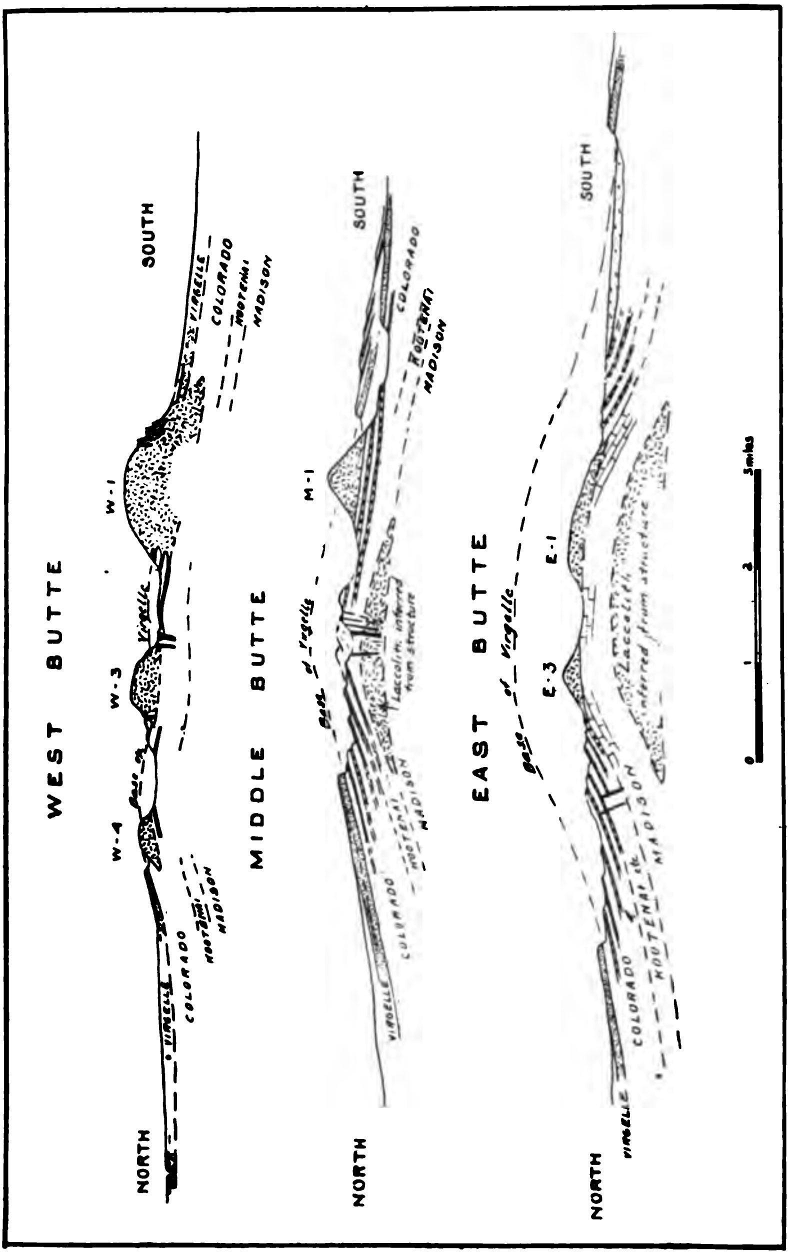

FIGURE 2.—Structure Sections

WORK OF A. R. LEDOUX

The Hills were visited in the summer of 1890 by Dr. A. R. Ledoux with the purpose of examining some iron ore prospects on East Butte. At the meeting of the New York Academy of Sciences, February 9, 1891, Dr. Ledoux gave an interesting description of East Butte. Approaching one of its summits called Mount Morris, he records:[8]

"The ground is thickly strewn with every kind of igneous rock—dark green basalts, phonolite, and every variety of feldspar porphyry. . . . The mountain mass . . . is a grayish porphyry containing small feldspar crystals, but gashed and seamed by dike after dike of trap and large crystal bird's-eye porphyry. Between these dikes are older clay slates, mica schists, hornblendic schists, all inclined at a sharp angle and indicating clearly the intrusive nature of the mass."

The iron ore lay at the contact of porphyry and marble. Dr. Ledoux was thus impressed with the variety of the rocks present, and while he mentions phonolite without microscopic determinations, he was entirely correct. He also appreciated the contact effects.

General Petrography

As stated above, the earliest microscopic determinations of the rocks were made by Frank D. Adams for George M. Dawson in 1882-84. Referring to East Butte, Dr. Dawson speaks as follows:

"The rock is very uniform, lithologically, in appearance and composition. Mr. F. D. Adams has examined microscopic sections of it, and states that it may be called a hornblende-trachyte, rich in plagioclase. Mr. Adams writes: 'It is composed of orthoclase and plagioclase, both present in large amount, and some hornblende. It is therefore, intermediate in composition between andesite and trachyte, and to which class it may be best referred can only be ascertained by a partial analysis.' "[9]

This general determination by Dr. Adams holds very well for the main laccoliths. About ten years later, 1895, Dr. Dawson furnished W. H. Weed and L. V. Pirsson two specimens from West Butte which showed a weathered brown crust and some flowage structure in the arrangement

mapped the geology, as shown on the three figures—3, 4, and 5. We added some additional details in May, and since then Mr. Fowler has kindly filled out several gaps, more especially in East Butte. The rather extensive collections of igneous rocks have been worked up microscopically and the manuscript has been prepared by the senior writer. Over one hundred thin-sections have been cut and studied. The sedimentary strata have been described by the junior writer. We gladly take this opportunity of expressing our indebtedness to Mr. Fowler for many accurate observations and much enthusiastic help. We are also greatly indebted to Dr. Henry S. Washington for three complete analyses of the igneous rocks.

[8] Trans. N. Y. Acad. of Sci., vol. x, 1891, p. 59.

[9] Canadian Geological Survey. Report of progress, 1882-1884, pp. 46C, 47C. 1885.

of the components. The feldspar phenocrysts were 2 millimeters across. The minerals observed and recorded are apatite, hornblende, iron ore, plagioclase, orthoclase, and quartz. The plagioclase ranges from basic labradorite to medium acid oligoclase. The hornblende is the usual dark green color and is more or less decomposed. The groundmass is a fine grained, patchy or micropoikilitic mixture of quartz and feldspar, the latter usually too much altered or kaolinized for identification, but certainly composed in part of orthoclase. The quartz occurs also, at times, in irregular grains, which rise to the position of small phenocrysts. They therefore named the rock quartz diorite porphyrite.

Two specimens were also studied from East Butte. They are described as porphyritic, but as possessed of larger phenocrysts of flesh-colored feldspar (11 x 6 millimeters) than the specimens from West Butte. There are also small black augites. Under the microscope, zircon, iron ore, apatite, ægirine-augite, oligoclase, orthoclase, anorthoclase, and quartz can be recognized. The commonest phenocryst is orthoclase, frequently intergrown with anorthoclase. The groundmass consists of microgranitic alkali feldspar and quartz, with some small microlites which were suspected of being augite. While the obvious soda-rich character of the rock was recognized from the anorthoclase and ægirite-augite, the name quartz syenite porphyry was given to it. As the subsequent details will show, our much more extensive and representative collections fully bear out the soda-rich character of East Butte and have added the characteristic ægirite rocks, the tinguaites, as well as more acidic members.

Weed and Pirsson also describe as minette the dike rock from the plains some miles north of East Butte, which Dr. Dawson mentioned twenty years earlier as kersanton. The former found abundant phenocrysts of biotite up to 5 millimeters. Under the microscope, apatite, iron ore, biotite, augite, orthoclase, and calcite were recorded. The augite was sometimes associated with ægirite. This is really a remarkably interesting rock, which we also have studied. We find, however, additional sills and dikes of it, both in Middle Butte and East Butte, and some variations toward rocks with biotite still prominent, but not predominant.

The above earlier records have been cited in detail both to give proper acknowledgment to previous workers and to prevent unnecessary repetition. Laccoliths of rocks which show affinities with the trachyte-syenite series and the andesite-diorite series are widespread in the Rocky Mountains. They are frequently mentioned by Weed and Pirsson, but the ones in the Judith Mountains and in the Moccasin Buttes, lying east of them, are marked in their resemblance to the Sweet Grass types. The

FIGURE 1.—VIEW OF WEST BUTTE

The view is taken looking north 60 degrees west from a distance of four or five miles. The summit of the large dome is about 3,000 feet above the plains.

FIGURE 2.—THE PRECIPITOUS ESCARPMENT AT THE SOUTHEAST CORNER OF WEST BUTTE

WEST BUTTE, SWEET GRASS HILLS, MONTANA

laccoliths studied and described by Whitman Cross[10] from Colorado, Utah, and Arizona present many similarities. The Cerrillos Hills of New Mexico are practically the same rocks, as described by Douglas W. Johnson.[11] The resemblance to the laccolith at San José, Tamaulipas, Mexico,[12] is also striking and the association of soda-rich rocks is worthy of remark.

Structural and Stratigraphical Relations

GENERAL REVIEW

West Butte, on the map, figure 3, is shown as one specially large connected area of igneous rock, marked W. 1 and W. 2, and two other principal outlying laccolithic masses, W. 3 and W. 4. Unfortunately, in the preparation of this and the other geological maps, no topographic maps were available. The laccolithic mass, W. 1, is shown in profile as viewed from the southeast, in plate 7, figure 1. It is the loftiest summit in West Butte and exhibits a general outline almost theoretically perfect for a laccolith. Its northwestern extension, W. 2, is much lower. The rocks are very similar in both exposures, and it may be that the two summits are merely eroded parts of one great laccolithic mass. The steep escarpment which faces east, on the southeast corner, and which is illustrated by figure 2 of plate 7, is probably due to sheeting and weathering along a fault-line. Glacial plucking has doubtless helped to accentuate the relief, an inference strengthened by the incipient cirque shown in figure 1 of plate 8. On the south and west the dips of the fringing sedimentary strata are so low as to lead one to infer that the laccolith was tapering rapidly to its thin edge. The summits W. 3 and W. 4 are most probably small auxiliary laccoliths outlying from the main mass. They are separated from the main mass and from each other by depressions in which Colorado shales still survive. The bases of the exposed laccoliths are believed to rest on the Colorado shales, and the igneous rock at its intrusion presumably spread out laterally in this thick shale formation. The stratigraphical relations are shown by the section on figure 2.

Middle Butte is contrasted with both the others in having its main

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[10] Whitman Cross: The laccolithic mountain groups of Colorado, Utah, and Arizona. U. S. Geol. Survey, 14th Ann. Rept., pt. ii, 1894, pp. 165-241.

[11] D. W. Johnson: Geology of the Cerrillos Hills, New Mexico. School of Mines Quarterly, vol. 24, pp. 173-246, 303-350, 456-500, and vol. 25, 1893, pp. 69-98. The last part, on the petrography, is of especial interest in this connection. The present senior writer spent a week in the field with Dr. Johnson in 1892 and vividly recalls the similarities.

[12] J. F. Kemp: The copper deposits at San José, Tamaulipas, Mexico. Trans. Am. Inst. of Mining Engineers, vol. 36, 1906, pp. 178-203.

J. F. Kemp and G. I. Finlay: Nepheline-syenite area of San José, Tamaulipas. Bull. Geol. Soc. Am., vol. 14, 1904, p. 534.

central area Colorado shales, which, with numerous sills, still forms the surface. Its profile, when viewed from the northwest, is shown in figure 1 of plate 9. The outstanding feature is the sharp cone, illustrated also by figure 2 of plate 9 and figure 1 of plate 10. This cone is the remnant of a laccolith which probably was once more domelike in outline. It rests, however, on Colorado shales, as shown in the section, figure 2, and, as did the intrusive masses of West Butte, the uprising molten rock spread laterally in these relatively soft shales. Several large sills came out much lower in the Colorado formation. The other laccolithic exposures, M. 2 and M. 3, are very much lower in altitude, but the general character of the great doming uplift gives ground for inferring a very large laccolith, presumably with its base on the Madison limestone and spreading laterally in the Kootenai shales and sandstones. The many sills of the central area support this view, and it has been adopted in the section of Middle Butte in figure 2.

East Butte is the largest of the three uplifts and is shown in profile, as viewed from the west, in figure 2 of plate 12. It has several quite lofty and impressive summits, which in the past have received separate names. The bases of the laccoliths rest on the Madison limestone, so far as our observations go, and the igneous magma spread laterally in the Kootenai shales and sandstones. E. 1 and E. 2 of figure 5, while separate summits, are apparently parts of one intrusive mass. E. 3 stands up in a strongly marked cone, as shown in figure 2 of plate 12. E. 6 is also a striking summit, as brought out by the same view. One narrow, continuous exposure of igneous rock connects E. 3 and E. 6. It may be that they are residues of one parent mass. The long, straight, northwest boundary of exposure E. 4 suggests a fault, and the relations of it to the other exposures is thereby obscured. E. 5 would appear to be a small outlying laccolith in the Colorado shales 2 miles east of the main exposures. Haystack Butte is another at the same horizon and 4 or 5 miles to the southwest. Numerous sills, many of them minette, surround the central area and are especially well exposed in the valley which heads up south of the Strode ranch. The minette dike, 4 or 5 miles to the northeast, is the remotest outlying dike of which we have knowledge around the Hills.

WEST BUTTE

Speaking in general summary of West Butte, the rocks constituting the main laccoliths and the sills are all porphyritic or felsitic in texture. Typical granitoid textures we have not met. The feldspars are the predominant and may rarely be the only, phenocrysts, but there are frequent instances in which the ferromagnesian (mafic) minerals appear promi-

FIGURE 1.—VIEW OF SOUTH LACCOLITH OF WEST BUTTE

The view is taken from the east at a distance of one mile. An incipient cirque appears on its east front.

FIGURE 2.—VIEW OF SILL OR SMALL LACCOLITH WHICH FURNISHED SPECIMEN NUMBER 8, WEST BUTTE

WEST BUTTE, SWEET GRASS HILLS, MONTANA

FIGURE 1.—DISTANT VIEW OF MIDDLE BUTTE, LOOKING SOUTHEAST

FIGURE 2.—VIEW OF LACCOLITH M. 1 OF FIGURE 4, ALSO CALLED GOLD BUTTE

The view is taken looking due east. The conical laccolith rests on the Colorado shales. A thick sill in the Colorado shales runs from left to right across the middle foreground.

MIDDLE AND GOLD BUTTES, SWEET GRASS HILLS, MONTANA

nently among them. The ferromagnesian (mafic) minerals are always of smaller size than the feldspars. We have not found quartz among the phenocrysts, and can safely state that it is, at most, rare. The rocks, therefore, do not reach the percentages in silica characteristic of the

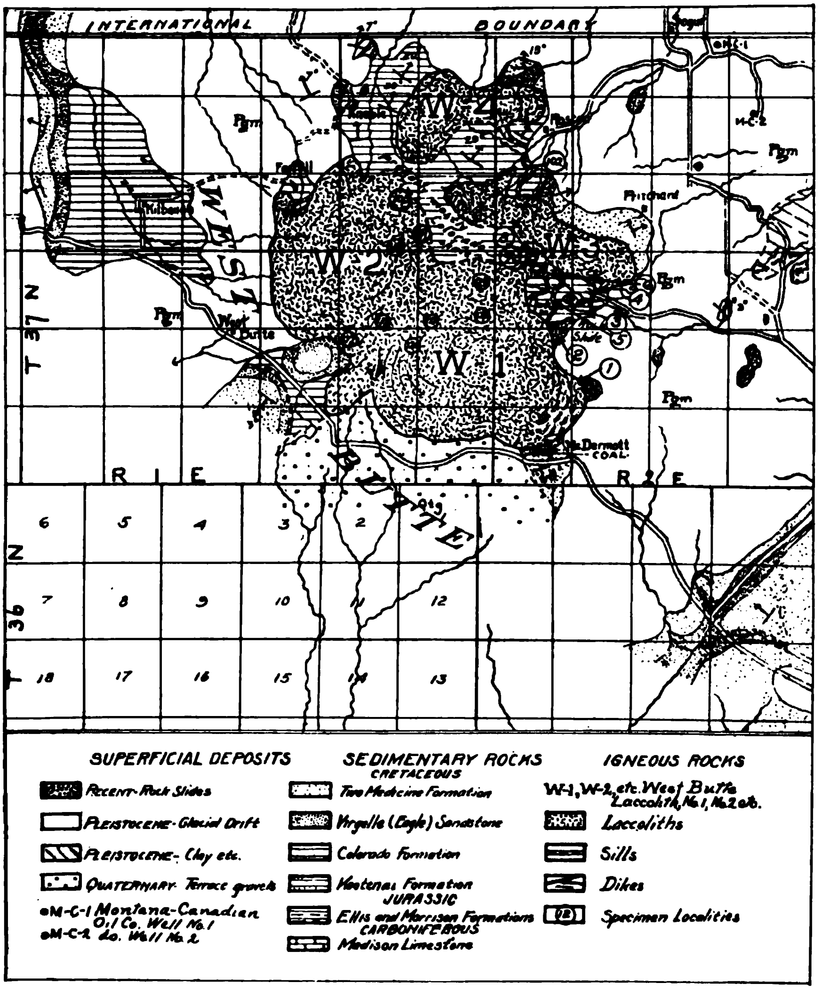

FIGURE 3.—*Geological Map of West Butte*

rhyolite-granite series. Both orthoclase and plagioclase appear among the phenocrysts. In some slides one predominates, in some the other. It is improbable that, in any exposure of porphyritic rock, either one absolutely fails, but the orthoclase certainly sinks at times to a very small

amount. There is one locality, specimen 118, on the southwest corner of West Butte, where the orthoclases reach a full inch in diameter and predominate in the rock. The plagioclases, in our experience and as stated by Weed and Pirsson, range from oligoclase to basic labradorite. Both orthoclase and plagioclase are beautifully zonal in many instances.

The ferromagnesian (mafic) mineral which may be taken as characteristic of the type is hornblende. It may be practically the only one present. There is, however, a constant tendency of augite and biotite to join it and for augite to exceed it. The augite is commonly the ordinary green variety, but, by increasing pleochroism and by the characteristic emerald green color, the presence of the ægirite molecule is suggested at times. Augite may become so abundant, combined with increase of basic plagioclase, as to give the rock a basaltic aspect and to remind one of latites and even of olivine-free diabases, but we have never detected olivine in the slides. The varieties may be considered merely basic extremes of the usual laccolithic rock. We have found no exposure of rock corresponding to the dark, basic yogoite of Weed and Pirsson.

The hornblende and the less common biotite of the thin-sections show resorption to partial or even complete reorganization, with the production of much finely granular magnetite. Augite has escaped the resorption and at most has narrow rims accentuated by grains of included magnetite. From the summit of laccolith W. 1 we have one slide, number 121, which has a small fragment of an older and more basic, biotite-bearing variety included in the later feldspathic porphyry. The inclusion is a reminder of an earlier crystallization of the magma.

The slides display decided variety in the groundmass, even from neighboring parts of the same laccolith. We find microgranitic texture in some. Others have rods of feldspars in recognizable flow-structures, reminding one of typical trachytic texture. The feldspars may be interlaced and fairly coarse rods of plagioclase, reminiscent of diabases, and may again assume stocky, rectangular shapes, almost square. From the east side of laccolith W. 2, specimen 116, and from the summit, specimen 117, have the stocky feldspars (plagioclase in these instances) in rude flow-lines. The latter has so much augite as to make a basaltic impression on the observer.

We have reviewed the laccolithic rocks of West Butte in detail because they furnish the most accessible collecting ground and are, on the whole, the best exposed. Along the precipitous front on the southeast corner, there is a huge talus of beautifully fresh rock which furnishes a very interesting exhibit and to which a visitor may resort with the best opportunity for hand specimens. From the talus (number 1 of figure 3) was

FIGURE 1.—THE SHARP CONE OF LACCOLITH M. 1 OF FIGURE 4

View is taken looking due north, with minette sill, number 39, in the middle foreground.

FIGURE 2. DETAIL OF SILL NUMBER 39

Showing the polygonal columns, unusual in the sills. The rock is minette, thickly set with inclusions of Precambrian rocks. The nearest exposures of Precambrian rocks are about 100 miles west.

GOLD BUTTE, SWEET GRASS HILLS, MONTANA

selected the sample which has been kindly analyzed by Dr. Henry S. Washington with the following results:

SiO_2	63.46	Na_2O	5.19
TiO_2	0.12	K_2O	3.56
Al_2O_3	16.83	H_2O+	0.83
Cr_2O_3	none	H_2O	0.03
Fe_2O_3	2.23	P_2O_5	0.28
FeO	1.88	SO_3	0.05
MnO	0.17	CO_2	none
MgO	1.13	ZrO_2	none
CaO	4.00	Cl	not det.
BaO	0.09		
		Total	99.85

The norm was calculated by Dr. Washington as follows:

Quartz	10.74	Hypersthene	2.22
Orthoclase	21.13	Magnetite	3.25
Albite	44.01	Ilmenite	0.30
Anorthite	11.95	Apatite	0.67
Diopside	4.86		

The symbol of the norm in the quantitative system is I (II) (4) 5.2.4; that is, the rock is transitional between class I, persalane, and class II, dosalane. Placing it with the former, it is again transitional between order 4, quardofelic austrare, and order 5, perfelic canadare. Giving preference to the latter, it falls in rang 2, domalkalic pulaskase, and subrang 4, dosodic larvikose.

The obvious difference between the theoretical norm and the actual mode is the presence of hornblende with probably subordinate augite and possibly a shred or two of biotite, whereas diopside and hypersthene are mentioned in the norm. In general we may say that the light-colored components are 87.83 per cent by weight; the dark-colored ones, 11.30. By volume, the preponderance of light-colored would be slightly greater—somewhere about 8 to 1. Orthoclase is in the ratio to plagioclase of 21.13 to 55.96, or about 1 : 2.5; but alkali feldspar molecules are to anorthite as 65.14 : 11.95, or about 5.4 : 1. Quartz diorite porphyry would thus quite well describe the rock, in the ordinary nomenclature.

In the huge talus of loose rock from the solid laccolith on the southeastern side of West Butte we have collected many specimens with dark angular inclusions which represent wall rocks of the supply conduit picked up in the passage of the magma upward. Some appear to represent hornblendic gneiss, presumably from the basal Precambrian; others are dark femic aggregates which may be recrystallized limestones or calcareous shales. Specimen 2*b* is a quartz diorite porphyry with an in-

[Chara]cteristic Outcrop of a Dike, radiating from the Laccolithic Center, [We]st of Gold Butte Post-Office, on Map, Figure 4

[Dikes] in benches with thin sills, appear on the right, with the north end of Middle Butte in the background.

Figure 2.—Dike Number 24, west of Gold Butte Post-Office, Figure 4

This is a view of two dikes, crossed by a gulch following a fault, which offsets the front dike so as to open it like a gate.

DIKES IN THE SWEET GRASS HILLS, MONTANA

FIGURE 1.—PLATY PARTING OF A DIORITE-PORPHYRY DIKE, TWO MILES SOUTHWEST OF GOLD BUTTE POST-OFFICE

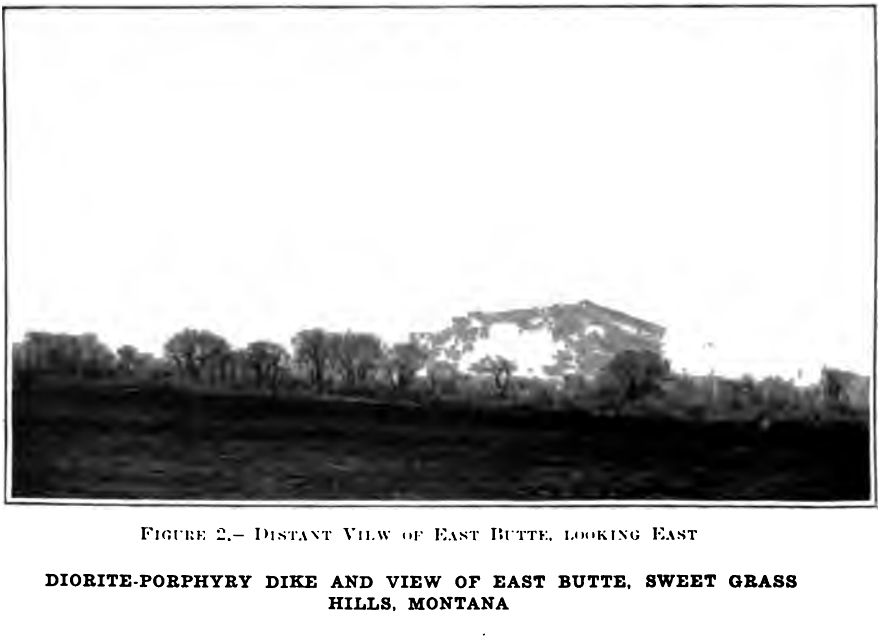

FIGURE 2.—DISTANT VIEW OF EAST BUTTE, LOOKING EAST

DIORITE-PORPHYRY DIKE AND VIEW OF EAST BUTTE, SWEET GRASS HILLS, MONTANA

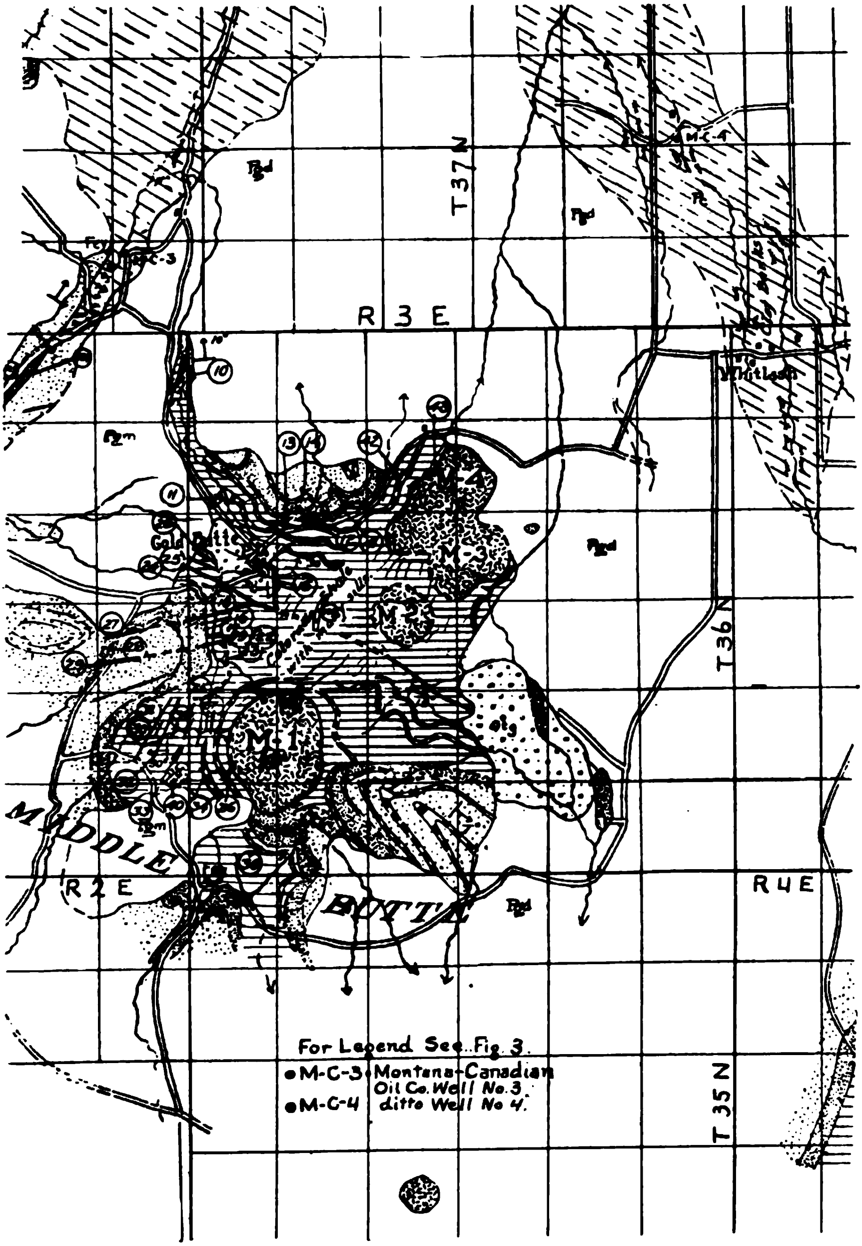

FIGURE 4.—*Geological Map of Middle Butte*

in the central portions, ferromagnesian minerals at the lower contact—indicate increasing basicity toward the bottom, but the contrasts are not so great as to develop yogoite below.

Of the other three laccoliths no specimens were gathered, although they have all been visited and mapped. To the eye, they seemed superficially like the larger southern one.

The dikes and sills present much greater variety than do the laccoliths. Among themselves the two groups display such similar varieties of rocks that there is no advantage in treating them separately. One can not reasonably expect, in associated small bodies of intrusives, any great contrasts, because some are parallel with the bedding of the sediments and some cut across it. At one extreme there is a type with large phenocrysts of green hornblende, with no other phenocrysts and, even under the microscope, with no other recognizable ferromagnesian components. The groundmass consists of multitudes of minute feldspar rods, which in the vast majority of cases are once twinned and have nearly or actual parallel extinction. Only a few clearly show multiple twinning. Alteration somewhat obscures the clearness of individuals. Flow-lines are well developed. There are some little groups and individuals of quartz. Magnetite and apatite are fairly abundant, and there are a few spots of secondary calcite, which, as the hornblende is notably unaltered, may represent thoroughly decomposed augites. From this extreme of trachytic character we pass to increasing amounts of augite and plagioclase in other dikes and sills, and to some variations in the texture of the groundmass, because of larger rods and stocky rectangles among the feldspars. We never find more than a little quartz, but often see much calcite of a secondary character. Biotite first makes its appearance in scattered shreds. On its increase it seems to replace the hornblende, and with the disappearance of the latter fairly pure augite-biotite varieties result. With the further increase of biotite it may be the principal and predominant phenocryst, and in some of the sills reaches a large size, over 10 millimeters in diameter. Augite is its favorite associate and orthoclase is so prominent as to make the rock a minette.

The most interesting sill of this character is the one numbered 39 on the map and situated on the south side of the upheaval, a short distance northeast of the Fey ranch. It is illustrated in both pictures of plate 10. It is about 30 feet thick and has separated into marked columns on cooling. The abundant biotite first catches the attention in the gray mass afforded by the weathering of a rock which is green when fresh. Under the microscope the biotite is not so prominent, but, while abundant, is associated with equal amounts of large and small augite, sometimes

zonally built with pale green centers and darker green rims, both, however, with large extinction angles. Rare hornblendes, five or six times as long as broad and of a beautiful green color, are likewise present. There are no feldspar phenocrysts, but in the groundmass the little rods, once twinned for the most part and with nearly parallel extinction, are the chief components. There is much magnetite, and frequent and fairly large, rudely prismatic, apatites are scattered among the small components. There are evidences that some rather large component has been resorbed, leaving magnetite skeletons, and there are rare residues of calcite and feebly refracting serpentine or chlorite, representing an original, now hopelessly altered. The rock may be best described as a minette, but it is not so rich in biotite as some others in and north of East Butte.

The most remarkable feature of sill 39 is furnished by the innumerable inclusions, up to 2 feet, in diameter, of Precambrian rocks. They can be seen obscurely in figure 2 of plate 10, and in places constitute a third or a quarter of the mass. As they are all resistant rocks, they show slight, if any, effects of absorption or digestion. They must represent either fragments along a fissure or zone of parallel fissuring through which the sill drove its way like a wedge, or else were stoped off as the magma ate its way upward. Among the fragments the following varieties were recorded: granite gneiss, hornblende gneiss, granite, quartzite, bits of pegmatite, garnetiferous granite gneiss, and mica schist. There were also rounded inclusions, which, in the one case studied, consisted chiefly of green, granular diopside at the center, with a black border of hornblende. The total diameter was 45 millimeters and the border 10 millimeters across. This inclusion was probably once limestone. In another of similar nature garnets were noted.

EAST BUTTE

In areal uplift East Butte is the largest of the three, and brings to the surface the Madison limestone, the oldest of the sedimentary strata exposed in the Hills. The limestone is domed up by the large southern laccolith, with its two peaks at E. 1 and E. 2, figure 5, and is penetrated by the more irregular bodies, E. 3, E. 4, and E. 6. Smaller outlying laccolithic masses appear around the main intrusions at higher stratigraphic horizons. The flanks of the uplift present a maze of sheets and dikes. Of especial structural interest is a veritable plug, 10 feet in diameter, which pierces the Madison limestone at specimen 125.

East Butte contains the rocks of greatest petrographic interest. There appears to be a progressive change in chemical composition in the outbreaks of the three buttes from west to east.

West Butte has the largest amount of the rocks which approach the diabases and basalts. Some of our slides from the summit of its main

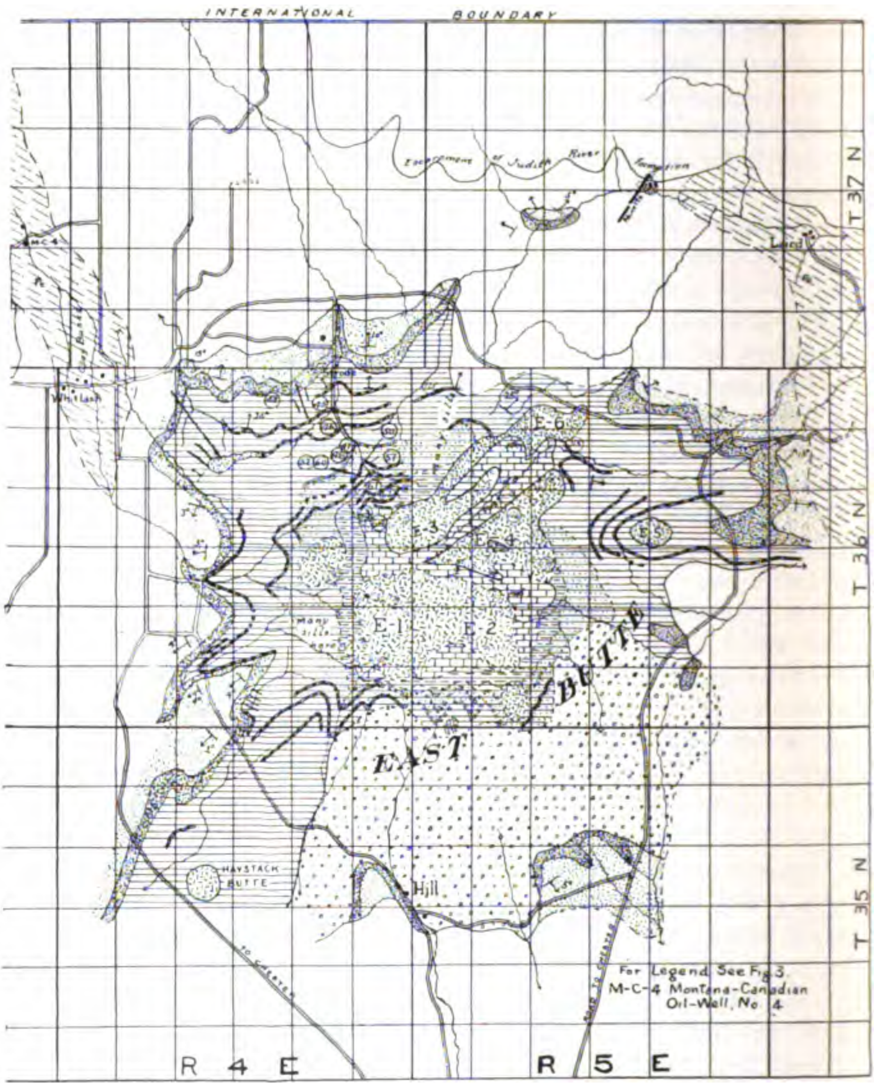

Figure 5.—*Geological Map of East Butte*

laccolith, as earlier remarked, are approximations to typical diabases. While there are exposures which might be correctly classed with trachyte porphyries or syenite porphyries, there are, so far as our studies have

gone, no ægirite rocks and no minettes. In Middle Butte we have similar conditions. The principal laccolith, M. 1, is a diorite porphyry, and among the sills and dikes are types all the way from trachytic to basaltic affinities. We only know of one minette, sill 39, on the south side. No ægirite rocks have been gathered. Although some of our specimens were felsitic in texture and greenish in color, the slides showed the green stain to be due to chlorite, not to ægirite.

As we come to East Butte and take up the slides of its main laccolithic summits, E. 1 and E. 2, ægirite in its characteristic green needles makes its appearance. The rocks have the familiar light green color of the tinguaites and lead the observer in the field to suspect at once rich soda and high alkali types. In the sills the trachytic and andesitic porphyries (respectively syenitic and dioritic) do not fail, but instances rich in orthoclase and approximating trachytic composition are more frequent. The extreme of the soda-rich ægirite rocks among those in our collection was obtained from a pipe or plug estimated by George M. Fowler, who gathered the specimen (number 125), to be 10 feet in diameter. A more complete description, with an analysis by H. S. Washington, will be given below. Minettes also are more abundant in East Butte than in the other two. The sills, numbers 46 and 48, in the Colorado shales, along the valley south from the Strode ranch, in the northwest corner of the uplift, are both minettes. Of 46 an analysis by Dr. Washington is later given. Dike 133, 6 miles north of the main uplift, is the minette collected by Dr. George Dawson and described petrographically by Weed and Pirsson, as earlier stated.

The rock of the laccolith having the two summits, E. 1 and E. 2, is porphyritic in texture, with phenocrysts at times of relatively large size. Under the microscope they are predominantly orthoclase, although plagioclase does not entirely fail. The orthoclase is often zonal and may reach a centimeter in diameter. Rarely quartz has been observed large enough to be placed with the phenocrysts and favoring the borders of orthoclase. The phenocrysts may attain such abundance that the groundmass appears as if it were relatively narrow channels amid islands. The larger dark silicate is augite, not always satisfactorily fresh. Its peculiar green suggests the presence in it of the ægirite molecule. Away from the lower contacts it is not abundant, but it does increase appreciably in the specimens taken along the northern, lower border of the laccolith.

The groundmass is microgranitic and consists of feldspars, quartz, and the tiny green needles of ægirite. The feldspar is predominantly untwinned and is probably a soda-bearing orthoclase. It favors square cross-sections to a degree worthy of remark. In instances extinction directions

have been found which followed the diagonals of the square, suggesting that the crystals were bounded by the unit clino-dome and elongated on the *a*-axis. The quartz is subordinate and of irregular outlines. Its presence eliminates the possibility of nephelite in the rock. The ægirite forms the usual felty, interlacing mass of minute green needles. An occasional grain of magnetite may be detected.

These rocks recall at once the soda-rich varieties studied by W. C. Brögger in the vicinity of Christiania and described in the classic monograph on the "Minerals of the Syenite-pegmatite Dikes."[13] Grorudite was applied to a dike rock whose phenocrysts were microline and ægirite and whose groundmass consisted of rectangular orthoclase, quartz, and ægirite. We do not find microline in the Sweet Grass rocks. The albite molecule has presumably remained in solid solution in the orthoclase[14] and has not exercised its influence either in the development of microline or microperthite. Aside from this difference, the rocks just described are obviously closely akin to grorudites.

In the irregularly shaped sill or partly exposed laccolith E. 4, the ægirite fails, so far as our three slides give the data. The rock is rather coarsely porphyritic, with abundant phenocrysts of orthoclase. Both augite and hornblende accompany it. The hornblende is a beautiful dark green to brown variety, in six-sided crystals with almost parallel extinction. The rock is rich in titanite, a rather infrequent mineral in the other salic types. The groundmass is composed of square and rectangular orthoclases, or at least untwinned feldspar, making the rock a very good syenite porphyry. Magnetite is also a small component.

SOME PETROGRAPHIC DETAILS

Tinguaite.—Just north of this last exposure, and penetrating the Madison limestone in the brook valley, is the plug of green rock, number 125. It is strongly porphyritic, having abundant shining, white, rectangular feldspars, 5 to 15 millimeters in long dimension, set in a dense green groundmass. Shining, black prisms of some ferromagnesian mineral, 0.5 millimeter wide by a maximum of 2 millimeters long, can also be detected.

Under the microscope the feldspar phenocrysts are apparently all

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[13] W. C. Brögger: Zeitschrift für Krystallographie, vol. xvi, 1890. On grorudite, p. 65. On sölvsbergite, Eruptivgesteine des Kristianiagebietes, I, 1894, p. 67. Sölvsbergite has much less quartz than grorudite or none at all. In other respects the mineralogy is much the same, involving alkali feldspar (mostly albite and microcline) with ægirite. In more basic varieties, hornblende (kataforite) replaces ægirite, with sometimes a peculiar mica. When quartz fails altogether, nephelite may appear.

[14] The feldspars are discussed from the standpoint of physical chemistry and the conceptions used in metallographic studies by H. L. Alling in vol. xxix, no. 3, 1921, of the Journal of Geology.

orthoclase. Multiple twinning fails, but the crystals are inclined to develop partially altered centers, giving them a muddy aspect. The dark phenocrysts are beautiful yellow-green ægirites or ægirite-augites, with very excellent crystal outlines, twins and zonal structure. Pleochroism ranges from yellowish green to yellowish brown. The groundmass is the usual felt of fine green ægirite needles, showing flowage arrangement and set in an isotropic or very feebly refracting basis. The whole aspect is the characteristic one of the tinguaites. One can not resist the belief that nephelite is present, or at least analcite, but gelatinizing tests with the pulverized rock, both by the senior writer and by H. S. Washington, when making the analysis given below, failed to afford satisfactory results. The combined water is so low, 0.45, that the amount of possible analcite would be small. The analysis shows the silica to be rather high for good nephelite or analcite rocks, while at the same time one can not well recast it without using one molecule or the other. Analyses of two other American rocks of related character are placed beside it, both going even slightly higher in silica and also in alumina, but lower in the other bases. The suggestion may be made that, as we are dealing with a pipe only 10 feet in diameter, the uncrystallized residue may have chilled into a glass which, had it broken up into minerals, would have afforded both feldspars and nephelite or analcite. No quartz whatever has been detected in the rock.

	I	II	III
SiO_2	59.39	57.46	57.63
TiO_2	0.58	.60	.23
Al_2O_3	14.65	15.40	17.53
Fe_2O_3	4.58	4.87	3.46
FeO	1.40	.87	1.18
MnO	0.13	tr.	tr.
MgO	0.70	1.37	.22
CaO	2.39	2.59	1.35
Na_2O	7.68	5.48	5.80
K_2O	8.25	9.44	9.16
H_2O+	0.45	.82	3.22
H_2O-	0.11	.09	
P_2O_5	0.13	.21	....
	100.44	99.20	99.78

I. Tinguaite pipe, East Butte, Sweet Grass Hills. Specimen 125. Analysis by H. S. Washington for this contribution.

II. Tinguaite dike, Bean Creek, Bearpaw Mountains, Montana. Weed and Pirsson. American Journal of Science, 1896, volume II, page 192. H. N. Stokes, analyst. Also Cl, .20; SO_3, 13; CO_2, .13; BaO, 60; SrO, .16; making a total of 100.42.

III. Tinguaite dike, Cone Butte, Judith Mountains, Montana. As under II. L. V. Pirsson, analyst. Also Cl, .08; making a total of 99.86.

These analyses have many points of similarity. The one from East Butte is about 2 per cent higher in silica than the others, but analyses of phonolitic rocks can be easily found which go higher yet in silica. The East Butte rock is the richest in alkalies of the three. Dr. Washington recast the analysis so as to make the rock's formula in the quantitative system II, 5(6), 1.3″ and the norm:

Orthoclase	48.93	Diopside	7.36
Albite	16.24	Wollastonite	0.93
Nephelite	7.10	Ilmenite	1.06
Acmite	13.40	Apatite	0.34
Sodium metasilicate	4.76		
		Total	100.12

Minette.—Among the most interesting of all the rocks in the Sweet Grass Hills are the rare rocks, minettes, which appear in sills and dikes. One sill has already been cited from Middle Butte, where there are one or two others. Several sills were mapped in the valley leading south toward East Butte from the Strode ranch. Of these number 46 has been selected as the best case for description and for the analysis, kindly made by Dr. H. S. Washington. The rock forms a sill in the Colorado shales and is cut across and beautifully exposed by the creek valley. It is dark gray in color and richly spangled with shining, black phenocrysts of biotite, up to a centimeter and more in diameter. In almost, but not quite, all cases the biotites lie parallel with the walls and give to the minette the characteristic resemblance to a biotite schist. In thin-section the most impressive mineral is the biotite, which is a rich golden brown color. It is very often in well bounded, six-sided platy-crystals. Some slight bendings from flowage may be detected. Augite is far less abundant and in much smaller crystals. It is pale green and has the usual high extinction of common augite. There are no feldspar phenocrysts. Magnetite grains are richly scattered through the rock. As is so often the case with the basic, biotite-rich rocks, apatite is abundant and of relatively large size. The cross-sections indicate stocky hexagonal prisms up to .2 millimeter in height and diameter. One titanite of rather large size for this mineral was detected. In the groundmass rods of an untwinned, colorless mineral, believed to be orthoclase, may be identified, but no plagioclase was detected. As is such a frequent experience with minettes, there is a large amount of secondary carbonates, and there is also a rather frequent development of clear, apparently secondary quartz. Green chloritic alteration products are not lacking. Dr. Washington's analysis resulted as is given under I. Under II and III are other minettes from the laccolithic mountains of Montana.

	I	II	III
SiO_2	49.98	52.26	46.04
TiO_2	1.24	.58	.64
Al_2O_3	12.91	13.96	12.23
Fe_2O_3	2.49	2.76	3.86
FeO	4.21	4.45	4.60
MnO	.17	.14	....
MgO	7.03	8.21	10.38
CaO	7.65	7.06	8.97
Na_2O	2.64	2.80	2.42
K_2O	5.02	3.87	5.77
H_2O+	1.78	1.34	2.87
H_2O-	.57	1.53	....
CO_2	2.84	.49	....
P_2O_5	.86	.52	1.14
BaO	.43	.23	.48
SrO	not det.	.05	.25
SO_3	.09	not det.	tr.
	99.91	100.25	99.65

I. Minette, East Butte, Sweet Grass Hills. H. S. Washington, analyst.

II. Augite-minette, Sheep Creek, Little Belt Mountains, Montana. L. V. Pirsson, U. S. Geological Survey, 20th Annual Report, Part III, 1900, page 531. W. F. Hillebrand, analyst.

III. Minette Arrow Peak, Highwood Mountains, Montana. L. V. Pirsson, U. S. Geological Survey, Bulletin 237, 1905, page 145. H. W. Foote, analyst. Also Cl, 11; total, 99.76.

In the East Butte minette, when one endeavors to recast the analyses, the 2.84 CO_2 and the 1.78 combined water reveal such advanced alteration as to make the determination of either mode or norm a matter of uncertainty. One only needs, however, to compare and study the analyses in order to realize the close similarities which prevail among the several occurrences. The descriptions corroborate the conclusions from the chemical analyses. The same minerals, the same textures, and the same alteration products appear in all three cases.

Along the valley to the south of number 46 are other sills and some dikes, among which minettes appear not infrequently. Number 49, just beyond number 48 of the map, is a variant from the typical variety. There is much less biotite and, under the microscope, quite as much augite as biotite. Hornblende does not fail, nor is plagioclase altogether lacking. The small minerals—magnetite, apatite, and microlites of augite—are important in the groundmass. The sill contains many inclusions of granite and some quartzite, both presumably Precambrian. There are also inclusions of the types of rocks found in the laccoliths, proving the sill to be a later outbreak than are they.

In this valley are various other types of rocks in the dikes and sills, among which the slides show a wide range from trachytic mixtures of hornblende and orthoclase, through variations with augite, biotite, and plagioclase, one or several, in different relative amounts. Once one understands the variations, detailed descriptions and elaborate nomenclature become unduly tedious.

In an exposure at number 52, of figure 5, on the west side of the valley, the intersecting dikes and sills illustrated in figure 6 were sketched. They are igneous rocks of at least two ages. Kootenai shales and a bed of sandstone are the wall rocks. Apparently the oldest rock is a minette—half sill, half dike—which cuts the lower exposure of shale and feathers

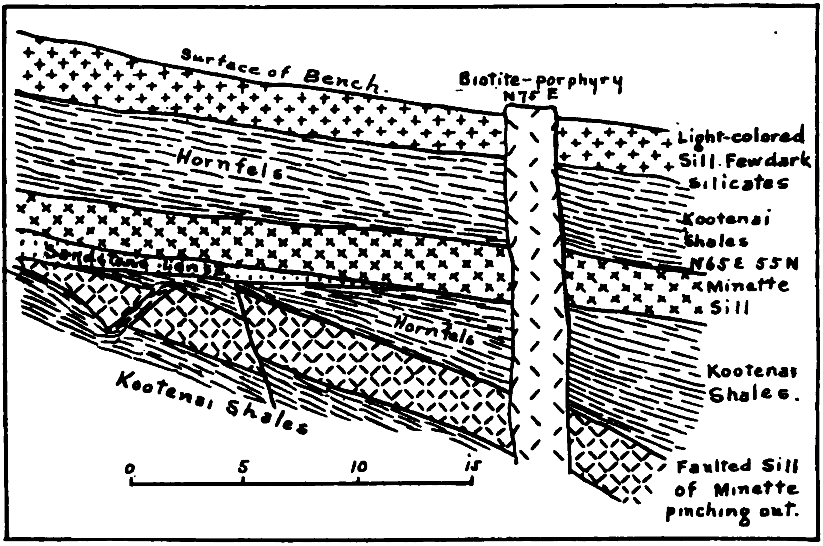

FIGURE 6.—*Types of Dikes and Sills*

out at the overlying sandstone. It is twice faulted in a small way, a feature exhibited by some of the other igneous masses. A sill, also of minette, lies above the sandstone bed, but presents some microscopic features unlike any other rock studied from the Hills. The usual large crystals of biotite are quite richly developed. In the groundmass, however, rods of orthoclase up to 0.3 millimeter are arranged in radiating rosettes and starlike aggregates. Other rods exhibit flow-lines. Apatite is strikingly abundant. Masses of carbonates still preserve the outlines of augites. Pyrite is not infrequent. At the top of the series is a light-colored sill, of much more feldspathic rock than the others, but it has not been examined microscopically. All the sills are cut by a dike of biotite porphyry, meaning by the term a trachytic rock. The scale is in feet.

Contact effects.—In a small gulch, just east of Gold Butte Post-Office, on the west side of Middle Butte, some contact effects of poorly exposed small dikes or sills have given rise in former years to a little prospecting by pits and a shaft. The intrusives have penetrated the Colorado shales; have changed them to hornfels, with accompanying silicification, and have impregnated the rock thus affected with pyrite. A small prospecting shaft has been sunk, and from the dump instructive specimens can be collected. The igneous dike which has effected the mineralization is a hornblende-bearing minette. It contains relatively large biotites and hornblendes in a groundmass of fine feldspar rods, predominantly orthoclase. Much magnetite and coarse apatite are scattered throughout the slide. The igneous rock is frozen tightly to the shale, and obviously following its entrance and consolidation, after-effects, apparently by hot waters or vapors, were produced in both dike and shales. The contact is no longer sharply discernible, even under the microscope, being obscured by the silicification of both rocks. In the dike, while the large biotites among the phenocrysts and the small feldspar rods of the groundmass are only slightly changed, the hornblende phenocrysts have become chloritized, and then in instances have been replaced with pyrite. Around the pyrite the chlorite residues and secondary calcite appear. Throughout the groundmass are small, irregular bits of pyrite, which have probably taken the place of earlier magnetites. These changes are closely akin to those which have marked the course of mineralization at Butte, Montana; but at Gold Butte there is no appreciable sericitization, whereas at Butte this change is one of the most widespread features.[15]

In the shales silicification is marked for a foot or a few feet from the intrusive. It has spread along the favorable layers and has developed both chalcedony and quartz, sometimes destroying, sometimes preserving, the old fragmental texture. Pyrite entered with the solutions and sometimes forms small, stocky rings around quartz crystals or grains. In less altered shale the pyrite has spread outwardly along favorable layers and has formed minute lenses, which are in shape and relations extremely reminiscent of the large bodies of pyrite in slates and schists, which even in English we describe as "kieslager." Some silica accompanied the pyrite. No assays have been made by us of the pyritized rock, but down the small drainage system into which this particular gulch discharges are the old placer diggings which gave rise to the name Gold Butte.

The most extensive contact effects have been developed on East Butte, along the northern edge of the laccoliths E. 1 and E. 2. It is here that

[15] Charles T. Kirk: Conditions of mineralization in the copper veins at Butte, Montana. Economic Geology, vol. 7, 1912, pp. 35-82.

the iron ores were discovered which were described by Dr. A. R. Ledoux. Although once opened up by shafts and some drifting, the old, abandoned excavations have become inaccessible since Dr. Ledoux's visit in 1890. He describes the outcrop as appearing on the contact of the marbleized limestone and the porphyry. The outcrop was 40 to 50 feet wide and was visible for seven or eight hundred feet and might extend much farther. The surface ore sometimes showed copper stains. The samples yielded 60 per cent iron and were low in phosphorus. Dr. Ledoux's descriptions are thoroughly characteristic of the western deposits of iron ore on the contacts of intrusives with limestones.

Our specimens of the ore are magnetic and indicate magnetite as an abundant, if not the chief, component. Polished slabs reveal an intergrowth with specular hematite. The ore has many cavities and the polished slabs reveal innumerable small ones. In part, at least, the cavities represent associated pyrites, more or less copper-bearing, but now weathered away. Experience elsewhere leads us to anticipate that as the water-level is approached and passed in depth, the unaltered pyrites will be found. The upper portions of the deposit appear to be thoroughly oxidized. The presence of lime silicates, especially garnet, with the ore has been recorded. The specimens kindly collected for us by Mr. Fowler did not show them, and the senior writer regretfully states that materials have not been available for petrographic details. The exigencies of our field-work prevented further collecting.

It is unfortunate that this great ore body is as yet so remote from iron works and centers of population. The ore must remain as a reserve for the future. L. G. Westgate[16] has recently described very similar deposits in the Little Belt Mountains, near Stanford, 57 miles southeast of Great Falls. They are on the contact of intrusive porphyry and the Madison limestone; are chiefly specular hematite, with some magnetite; are low in phosphorus, and in most samples yielded above 60 per cent iron. In the Cordilleran region practically all the bodies of iron ore are now known to be of this character.

Other economic resources.—Thirty years and more ago interest in prospecting in the Hills was active. Dr. Ledoux speaks of gold-bearing quartzite traversed by him in ascending the southern laccolithic summit of East Butte, and that good colors were found in the gravels of gulches crossing it. This quartzite must have been one of the Jurassic or Cretaceous sandstones or shales locally mineralized by the igneous rocks. He also speaks of observing evidence of galena or gray copper near the

[16] L. G. Westgate: Deposits of iron ore near Stanford, Montana. U. S. Geol. Survey Bull. 715F, 1920, pp. 85-92.

summit of the southern laccolith, then called Mount Morris. We have collected at 110 of the map of East Butte a breccia of porphyry which is richly mineralized with cubical iron pyrites. It came from the Brown-Eyed Queen claim and obviously along a line of movement and crush. Reports of other sulphides in West Butte are current.

The most important object of mining today is a seam of coal at the McDermott mine, in the Virgelle or Eagle sandstone, at the southeast corner of West Butte. The seam is 2 feet thick and has been changed by the intrusives into what is locally described as a high-grade semi-anthracite. It is mined in a modest way for local consumption. Of the explorations for oil and gas in the strata surrounding the Hills mention will be made in the following discussion of the sedimentary geology by the junior writer.

SEDIMENTARY ROCKS[17]

STRATIGRAPHY

Erosion of the Sweet Grass Hills uplift has exposed formations which are buried under later deposits for scores of miles in every direction. (See figure 7.) Thus the stratigraphic sections which can be measured here form a very valuable connecting link in the knowledge of these formations. In this lies their chief interest and importance.

MISSISSIPPIAN

The section.—The oldest visible member of the sedimentary series is the Madison limestone, of Mississippian age, and the youngest is the Judith River member of the Montana group. The section included between these limits comprises the most interesting and economically the most important portion of the entire stratigraphic column in Montana. Above the Madison limestone, elsewhere in the State, are a series of rocks which have yielded petroleum at several horizons and which are at present being actively explored by the drill at scores of places, including the Sweet Grass Hills themselves. Any light that the section here can cast upon the extent, character, and thickness of these formations is therefore of immediate value.

[17] The subsequent pages are by Paul Billingsley.

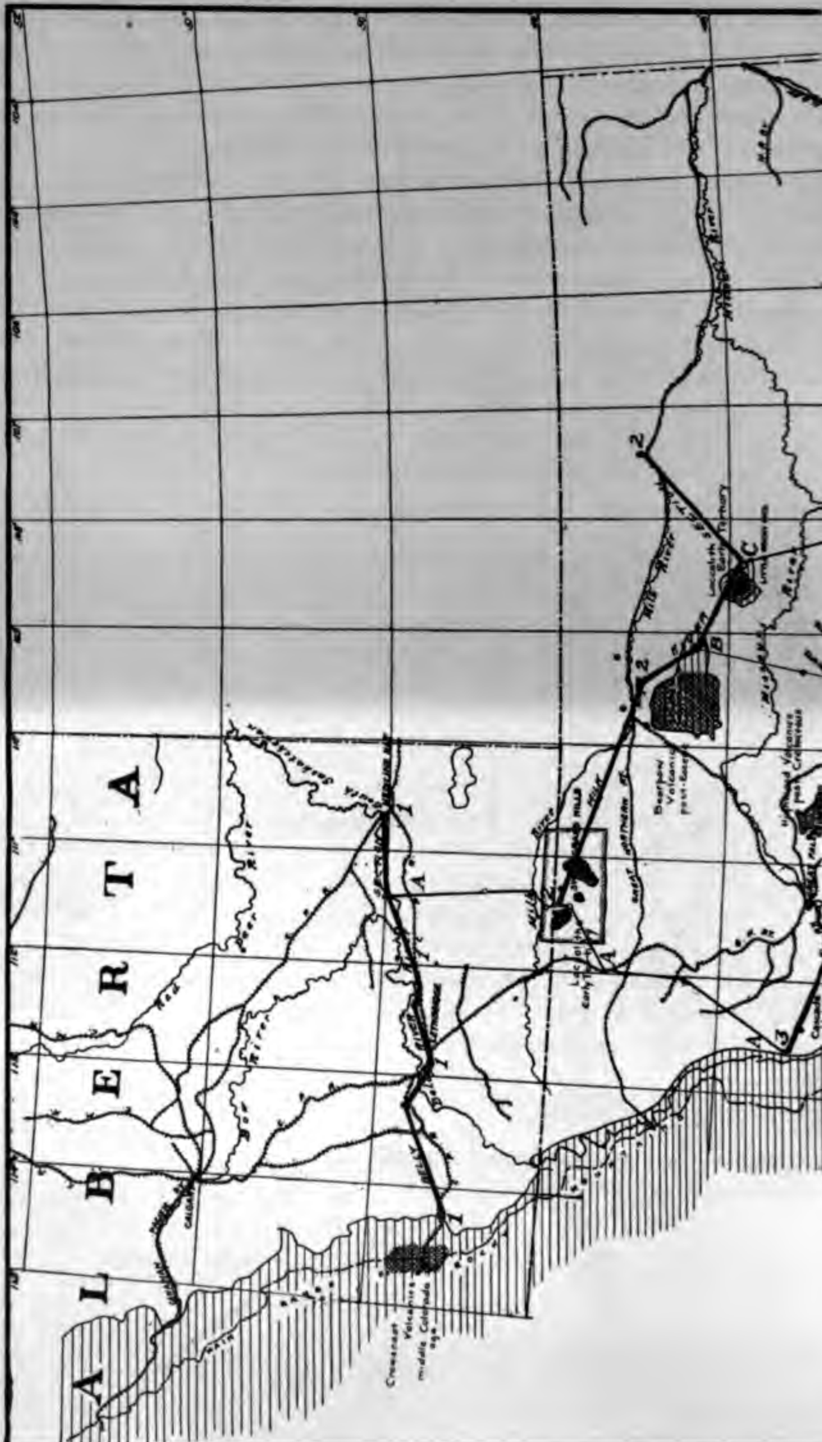
A L B E R T A

FIGURE 7.—Map of the Great Plains Region of Montana

The formations found in the Hills, with their thicknesses, are summarized below:

			Feet
Pleistocene	Glacial moraines. Glacial till.		
Upper Cretaceous	Montana group	Judith River	top eroded
		Claggett	500
		Eagle	150
	Colorado group	Upper member	1,000
		Lower member	800
Lower Cretaceous	Kootenai formation		450
Jurassic	Ellis formation		200
	Unconformity.		
Mississippian	Madison limestone		base not exposed

These will be discussed in order, from oldest to youngest.

Madison limestone.—The top of this widespread and uniform Carboniferous limestone is exposed on the north, east, and south slopes of East Butte. It lies at steep quaquaversal dips, being apparently domed up by a concealed laccolith, but also bears upon its upper surface the large laccolith which appears on the map. With intrusive rocks above and below, the formation is naturally considerably metamorphosed, and marble, magnetite, garnet zones, etcetera, occur at several points.

The Madison, so far as seen, consists of heavily bedded blue-gray limestone, with some lighter members bedded in layers about 2 feet thick. Since the top of the formation is an erosion surface and the base is not exposed, the thickness can not be determined, nor can even the relative place in the formation of the exposed section.

Overlying unconformity.—Normally, the Pennsylvanian, Permian, Triassic, and Jurassic formations should come above the Mississippian. In the Sweet Grass Hills is a gap extending to the Jurassic. This is not true of the greater part of Montana. In the Pryor Mountains, near Billings, above the Madison limestone, are Amsden red shales (Pennsylvanian), Tensleep sandstone (Pennsylvanian), Embar limestone (chiefly Permian), Chugwater red beds (Permian and Triassic), and Sundance (Ellis) limestone and sandstone (Jurassic). The strata between the Madison and Ellis have an aggregate thickness of about 1,200 feet.

Investigations in central Montana show that between the Pryor Mountains and the Sweet Grass Hills there is a steady change in the character and in the thickness of these intervening formations. The changes in

character are due to varying conditions of deposition; the variation in thickness in part to this, but for the most part to the removal by erosion, in Jurassic time, of the Triassic, Permian, and Pennsylvanian rocks from northwestern Montana.

The important changes in character are mainly within the Quadrant formation, which, in the Yellowstone National Park and central Montana, includes equivalents of the Amsden and Tensleep formations. The Amsden, Tensleep, and Embar formations and their approximate Montana equivalents, the Quadrant and Phosphoria, show great variation in thickness, even when this can not have been caused by the Jurassic erosion. The Amsden member is most persistent, being everywhere represented by a thin red shale at the base of the Quadrant. The Tensleep sandstone, on the other hand, diminishes from several hundred feet in northern Wyoming and southwestern Montana to a few feet only, near Billings, and either disappears entirely or is represented by shale in central Montana. The Embar, or impure limestone phase, with the phosphate horizon, merges eastward into the lower members of the Chugwater, as Condit has described[18], but northward becomes thicker and more shaly, exceeding 600 feet in Devils Basin, Cat Creek, and the Snowy Mountains. From this maximum it thins rapidly to the northwest, still uneroded, until in the vicinity of Lewistown it loses the protection of the overlying Chugwater formation and is stripped from the region north and west by the Jurassic erosion.

The Embar (and partly equivalent Phosphoria) is the probable source of most of the heavy oils found below the Cretaceous in Wyoming and Montana. Its distribution and character bear directly on the exploration for oil in the lower horizons. Hence its decrease in thickness in north-central Montana and its removal from the northern part of the State are facts of much importance.

The Chugwater formation, overlying the Embar, bore in Montana the brunt of the Jurassic erosion and is accordingly less widespread than the Quadrant. Thickest to the southeast, where it reaches 600 feet, it decreases northward, with the beveling off of its upper surface, to 400 feet near Billings (reference, Duck Creek well log), 320 feet in the Snowy Mountains (measured section), and 250 feet near Cat Creek (West Dome well, number 1). A thin-section of red beds with gypsum, overlying the Quadrant limestone at Belt Creek, may be an outlying remnant. Westward the Chugwater decreases to 200 feet in the Yellowstone Park and disappears near Gardiner. To the west and north of

[18] U. S. Geol. Survey Prof. Paper 98, 1916, p. 263.

the general line, Gardiner-Lewistown, there are no red beds between the eroded surface of the Quadrant limestone and the Ellis marine deposits.

The unconformity found in the Sweet Grass Hills section thus represents an erosion period which becomes greater from Wyoming to Alberta, uplift and denudation to the north being contemporaneous with continued deposition—first, marine (Quadrant); then under arid continental conditions (Chugwater)—to the south. As to the former extent of Quadrant and Chugwater deposits over the northern region, the Sweet Grass Hills section throws no light.

JURASSIC-ELLIS FORMATION

The sea, which finally covered the Jurassic erosion surface, deposited in the Sweet Grass Hills region about 200 feet of soft green shales, with some impure shaly limestones and calcareous sandstone layers. These deposits do not differ markedly, either in character or thickness, from the Ellis elsewhere. They suggest a shallow sea, but one with no contiguous high lands to supply coarse detritus. The Rocky Mountain uplift to the west had not yet commenced.

LOWER CRETACEOUS—KOOTENAI FORMATION

The Kootenai deposits, which rest conformably upon the Ellis, mark the first pronounced oscillation of level in the series of uplifts and subsidences which distinguish the Cretaceous age in the Rocky Mountain region. The record of these oscillations is nearly complete in the Sweet Grass Hills section and is the only such record within a radius of nearly 100 miles. For this reason the Cretaceous sections of the Sweet Grass Hills deserve a rather detailed study.

Three carefully measured sections are shown on the accompanying figure 8.

The general sequence from the base of the Kootenai is seen to be as follows:

1. Coarse sandstones deposited on the Ellis, becoming finer grained and interbedded with red and green shales (top of Kootenai).
2. Gray sandstones, sandy shales, and thin beds of dark shale, in the lower 400 feet of the Colorado.
3. Limy shales, shales with bentonite, and thin sandstone bands, ending with sandy shale and "shells" at 800 feet above the base of the Colorado.
4. Brown and blue shales, locally black shales, generally calcareous toward the top—the upper 1,000 feet of the Colorado.
5. Massive sandstone—the Eagle; generally has 2 to 4 feet coal bed on top.
6. Soft shale with sandstone layers, most numerous toward the west—Claggett.

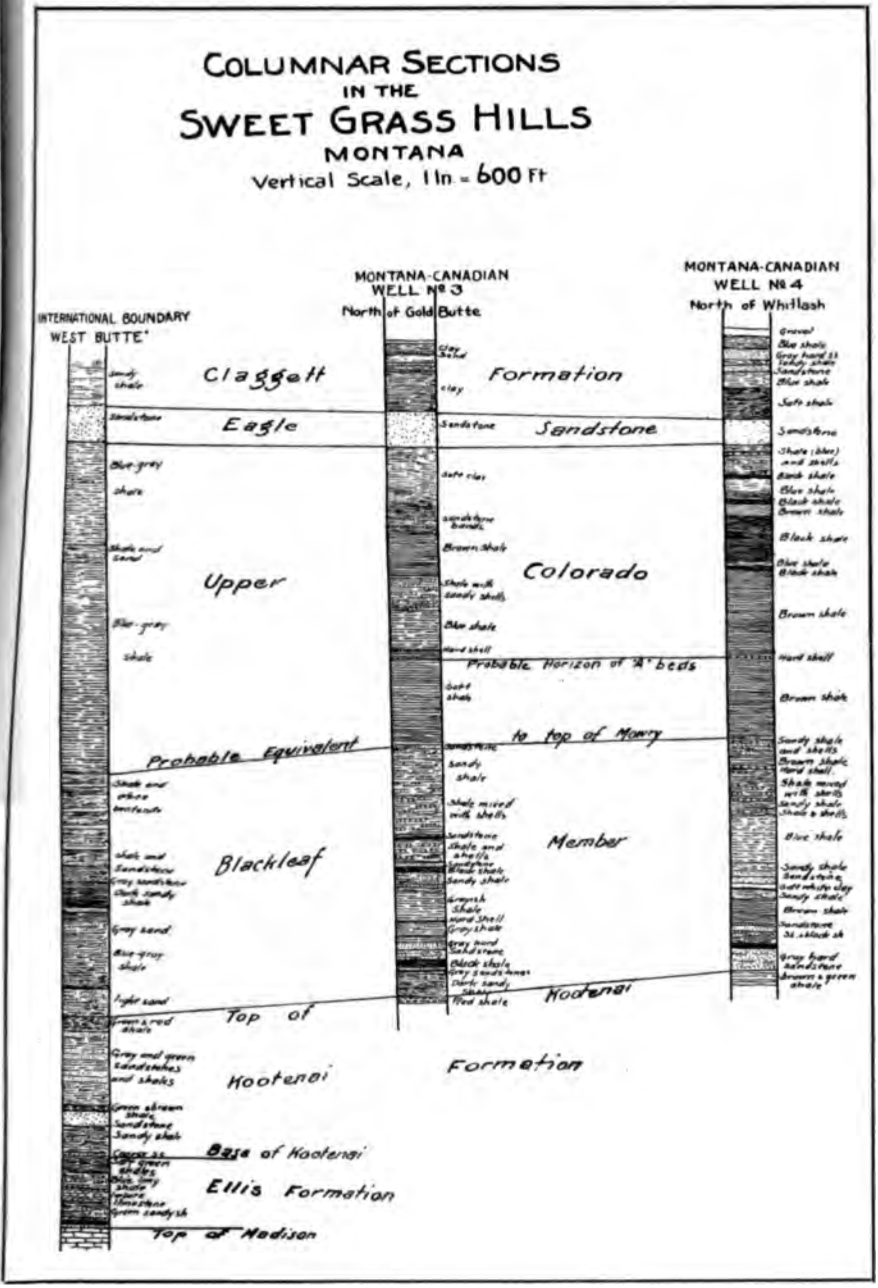

Figure 8.—*Columnar Sections in the Sweet Grass Hills, Montana*

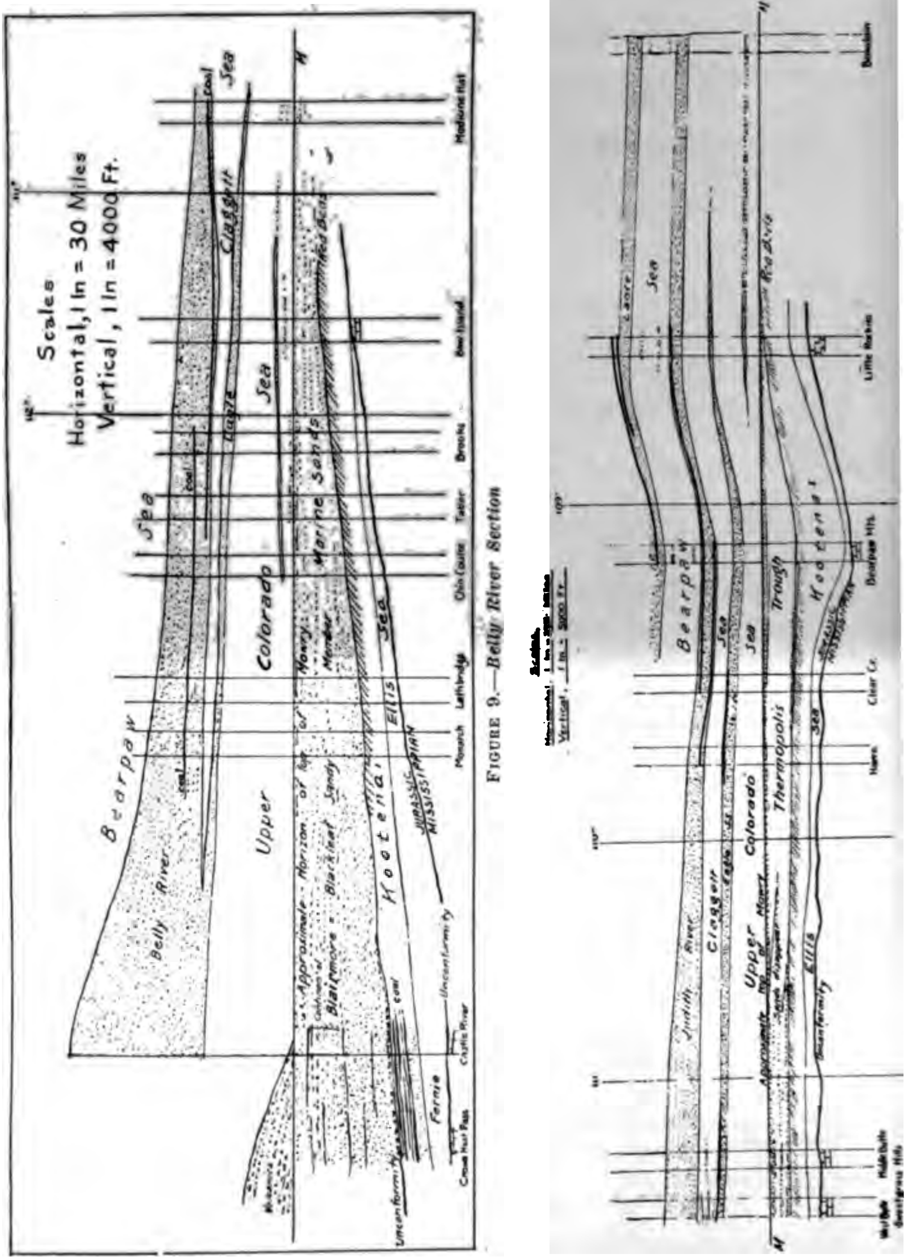

FIGURE 9.—*Belly River Section*

To show the correlation of these members with subdivisions already known elsewhere in the State, we have prepared a network of sections which ties together the representative areas. The form of this network is indicated on figure 7, and the sections themselves are given in figures 9 to 14, inclusive. The bases of correlation are several—in some areas one member, in some another—being most pronounced and readily identified. One member, however, the Mowry, has everywhere a typical character and a typical fish-scale fauna, and this member has been traced in the field without a break from Wyoming to beyond Great Falls, and where last seen here it occupies an horizon which can with little chance of error be located in the sections to the west and north. This gives a definite datum to which all the Cretaceous sections can be referred. With this preliminary explanation, we can pass to the descriptions of the members of the Cretaceous series.

In the Sweet Grass Hills the Kootenai formation consists of rusty-weathering brownish shales and buff to gray sandstones. Red color is pronounced only in the uppermost members, and even in them is much less here than to the south and east. The heavy sands at the base are associated with coal seams farther south and southwest, but no coal has been found in the Kootenai in the Sweet Grass Hills. One of the lower sands does, however, contain a tarry oil residue, both here and at several points to the north. The source of this maltha is an unsolved problem. Certainly, the Kootenai itself has no petroliferous or organic rich shales, and the Phosphoria is not present here. Possibly, farther north, the Kootenai rests upon petroliferous Devonian beds which were exposed by the Jurassic erosion, and oil from these might find its way into Kootenai sands and, after migration and the distillation of the volatile constituents, leave the tarry residue now found.

The Kootenai formation is about 450 feet thick—a thickness which it retains southward and eastward nearly to the borders of Montana. Westward, toward its source, it increases rapidly, reaching 3,900 feet in the Rocky Mountains near Crows Nest Pass, about 150 miles northwest of the Sweet Grass Hills.

UPPER CRETACEOUS

Colorado group.—The Kootenai formation is continental, trending toward arid conditions at the top; it is succeeded by the marine sandstones and shales of the Colorado group. These beds, generally soft and easily eroded, occur as a lowland belt about a mile wide, surrounding each butte, limited outward by an encircling rim of Eagle sandstone or a bench of Quaternary gravels. Most of the igneous masses of the

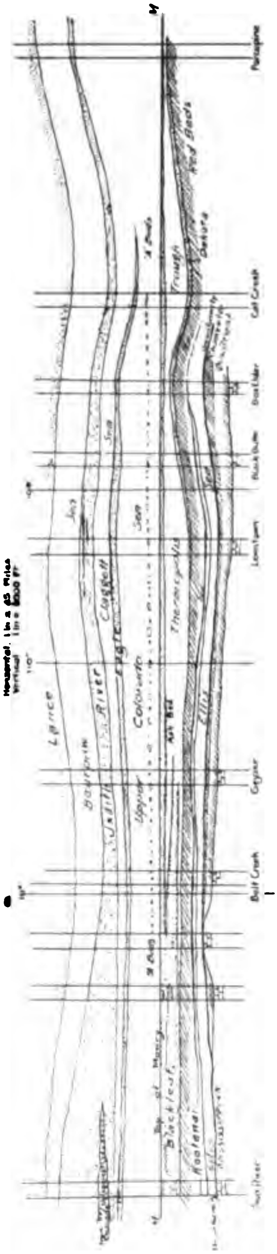

FIGURE 11.—*Great Falls-Cat Creek Section*

FIGURE 12.—*Musselshell River Section*

buttes—laccoliths, sills, and dikes—are within the Colorado beds. The main West Butte laccolith lies on lower Colorado strata and domes up upper Colorado; Middle Butte is formed of interbedded sills and lower Colorado shales; the outlying laccoliths of East Butte are between members of the Colorado. Such gas and oil as have been revealed by the drill are in the lower part of the Colorado formation.

In the Sweet Grass Hills, as generally, the basal member of the Colorado is a sandstone. Here it is about 75 feet thick and varies from "hard gray sandstone" to "dark sandy shale." Such a sandstone, resting on Kootenai red shales and succeeded by marine shales, is found in most of the Montana sections. It is absent only in a central belt running northwestward through Billings, Lewistown, and Great Falls. East of this belt the "parting" sandstone is present in the Bighorn Mountains, where it is the top of the Cloverly of Darton's reports, and in the Cat Creek oil field, where it is the "Cat Creek sand." To the west a sandstone between the red and black shales is found at Big Coulée, Shawmut, Sun River, Collins, and the Sweet Grass Hills. This sand is sometimes called Kootenai, sometimes Dakota, and sometimes Colorado—never, however, on fossil evidence, which is absent. It would seem logical to call the Cat Creek and Bighorn sandstone "Dakota," as it is almost certainly continuous with typical Dakota; to recognize that Dakota is absent in the central belt, and to tentatively call the lower sand in the western area "Lower Colorado." Since the Colorado Sea came in from the south and crept northward over the Kootenai land surface, its basal sandstone should be slightly more recent to the northwest.

Above the basal sandstone, in the Sweet Grass Hills, is a series of blue, brown, and black shales with numerous sandstone bands. This series is about 400 feet thick, above which the beds are more calcareous, but still have much sand, to a total thickness of about 800 feet, above the base of the Colorado. The top of this sandy phase is the horizon which, north and east of Great Falls, can be definitely correlated with the top of the Mowry member.

This means that the lower 800 feet of Colorado in the Sweet Grass Hills is the equivalent of the Mowry and Thermopolis formations of southern Montana and Wyoming. Their character has, however, changed in the long distance from the type localities. The Mowry has become more sandy; the shale of the Thermopolis is less bituminous and more sandy, and many thin sandstone layers have appeared. A glance at the general sections will show that this is the normal behavior of these formations to the north and west of their type localities in the Bighorn Basin of Wyoming. Sections 6 (Big Horn), on figure 14, and 5 (Yellowstone

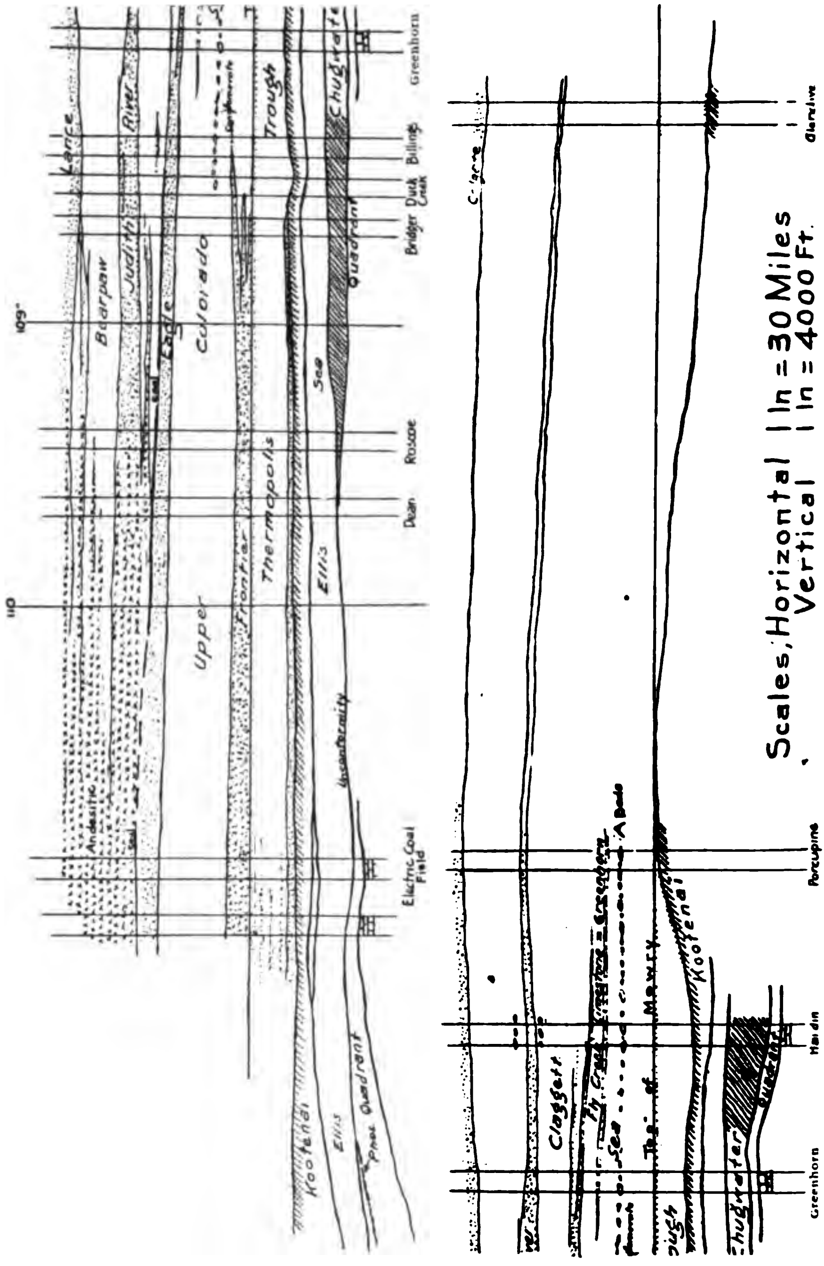

FIGURE 13.—*Yellowstone Section*

River), on figure 13, show that the typical Thermopolis black shale was deposited in a trough between Yellowstone Park and the Black Hills, with a shallow "reef" extending from the Big Horn northward to the Porcupine. On the east side of the trough the Thermopolis becomes very thin; on the west side it becomes sandy, due to the proximity of the Rocky Mountain shoreline.

This "trough" of bituminous black shale can be followed northward into Montana by referring to sections 4 (Musselshell River), on figure 12, 3 (Great Falls-Cat Creek), on figure 11, and 2 (Milk River), on figure 10. Each one shows the thinning out to the east and the increasing sandiness to the west, and on section 2, figure 10, the position of the Sweet Grass Hills relative to the Thermopolis trough can be seen. The final result of the increasing sandiness westward is shown on section 1, figure 9, the sandy Thermopolis grading into the Blackleaf phase, and this into the thick, partially continental Blairmore formation of the Canadian geologists.

To sum up, the early Colorado Sea entered Montana from the south, and first crept northward in an embayment now marked by the thick Thermopolis black shales. On the west, high lands supplied coarse detritus and sand, which were deposited along the western border, while the black shale was laid down in the center. On the east were no high lands, but probably a very shoal sea with no deposition.

These conditions changed under the impetus of a quick oscillation which first shoaled the sea, permitting fine-grained sand (Mowry) to be spread broadcast over the entire region, and then abruptly submerged the whole plains region to a depth which permitted the deposition of only fine calcareous shales over central Montana, with interbedded limestones east of Billings. The western shoreline retreated far west of the present Rocky Mountains. The Sweet Grass Hills sections reflect these changes. Above the sandstone that marks the top of the Mowry are brown and blue calcareous shales, with a very little black shale and almost no sandstone. The thickness of this member is 1,000 feet, and it represents the upper Benton and Niobrara stages of Cretaceous time.

Like the Thermopolis Sea, this upper Colorado Sea advanced from the southeast. The Mowry shoaling of the sea, which was most pronounced in the Yellowstone Park region, did not reach the Black Hills, and the deposits of the Upper Colorado Sea are far thicker in eastern and central Wyoming than in central and northern Montana. Being 3,200 feet thick at Basin, Wyoming, this formation decreases, as we have seen, to 1,000 feet in the Sweet Grass Hills. Its chief submembers in the southeast are:

1. Frontier member—sandy phase near base, best developed in the Bighorn Basin.
2. "A" beds—limy concretions at horizon about 200 feet above Frontier. Traceable from Black Hills to Great Falls.
3. Greenhorn limestone—thin, platy, fossiliferous limestone, traceable from Black Hills to Billings, about 300 feet above "A" beds.
4. Niobrara limestone—at top of Upper Colorado. Not distinguishable in Montana, but probably represented by uppermost 100 feet of calcareous shales in the Sweet Grass Hills section.

Montana group.—From the maximum marineward oscillation represented by the Upper Colorado, the pendulum of earth-movement swung back, with several breaks, to the maximum landward oscillation, represented by the Tertiary deposits. The Montana group of alternating terrestrial sandstones and marine shales is the expression of these movements.

The present knowledge of this group is based almost entirely on the painstaking work of a group of geologists of the United States Geological Survey. The earlier investigators were almost unavoidably confused by the repetition of similar formations, by the numerous obscure faults and the long stretches of Tertiary deposits, which concealed the Montana group. Thus G. M. Dawson, Hayden, Peele, and Weed were led to correlate formations similar in appearance, but as widely separated in time as Colorado, Claggett and Bearpaw or Eagle, Judith River, and Fox Hills. The true sequence was first made plain by Hatcher and Stanton,[19] and the stratigraphy of the group has been elaborated by Stebinger,[20] Bowen,[21] and Hancock[22]. Calvert and Stone[23] have attacked and solved the problem of the andesitic deposits of central Montana. The Montana group is one of the best known and most adequately interpreted in the region.

The Eagle sandstone is the lowest member of the Montana group. It is a light-colored, soft sandstone, about 100 feet thick, and is in the field the best horizon marker of all the upper Cretaceous members. It immediately underlies the surface for many miles to the west, north, and

[19] T. W. Stanton and J. B. Hatcher: Geology and paleontology of the Judith River beds. U. S. Geol. Survey Bull. 257, 1905.

[20] Eugene Stebinger: The Montana group of northwestern Montana. U. S. Geol. Survey Prof. Paper 90, October, 1914, pp. 61-68.

[21] C. F. Bowen: The stratigraphy of the Montana group, with special reference to the position and age of the Judith River formation in north-central Montana. Idem, February, 1915, pp. 95-153.

[22] E. J. Hancock: Geology and oil and gas prospects of the Lake Basin field, Montana. U. S. Geol. Survey Bull. 691, 1919, pp. 101-148. Geology and oil and gas prospects of the Huntley field, Montana. U. S. Geol. Survey Bull. 711, 1920, pp. 105-148.

[23] R. W. Stone and N. R. Calvert: Stratigraphic relations of the Livingston formation, Montana. Economic Geology, vol. 5, 1910, pp. 551-557, 652-669, 741-764.

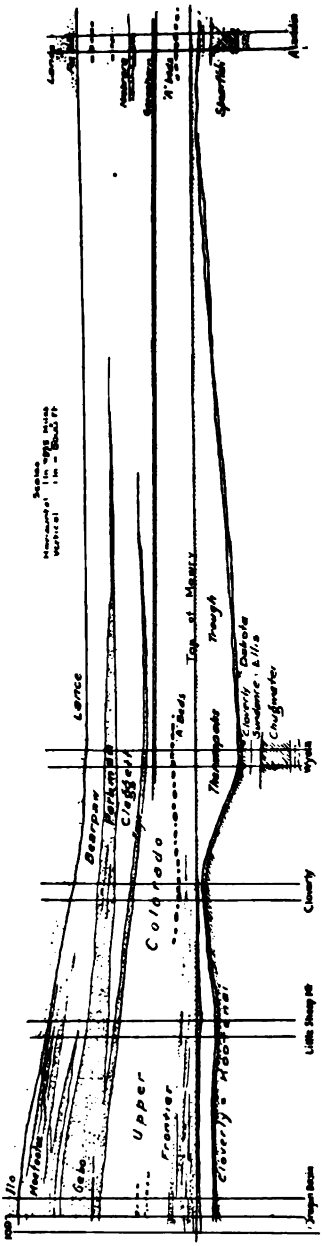

FIGURE 14.—*Big Horn Section*.

east of the three buttes, and the deeper coulées almost invariably cut into it, with resulting picturesque canyons. Around the buttes the Eagle is turned up in encircling rims which inclose the inner lowland of Colorado shale.

The change from the calcareous shales of the uppermost Colorado to the massive buff sandstone is very abrupt and bears witness to a rapid retreat of the sea and the spreading of Eagle as a retreatal sandstone. It is probably marine at the base, with seaweed casts and worm tracks, but near the top the coal bears witness to its emergence from the sea. On the southern edge of West Butte this coal, by reason of proximity to the intrusive rocks, has been metamorphosed into a high-grade semi-anthracite.

Above the Eagle, in the eastern part of the region, are marine shales, of which 259 feet were cut in Montana-Canadian well number 4. It is at least 200 feet above the collar of this well to the base of the Judith River beds, which cap the ridge to the northeast; so that, in all, about 500 feet of Claggett is here represented. In well number 1, however, north of West Butte, sandstone is practically continuous from the base of the Eagle up. Between these points, therefore, is the approximate shoreline of the Claggett Sea, where the marine shales give way to sands from the west. This shoreline can be traced southward through sections 3, 4, 5, and 6.

This completes the list of formations which are represented in their entirety in the Sweet Grass Hills region. The sections there seen fix definitely the following important facts:

1. The extent of Jurassic unconformity and erosion.
2. The character of the Mowry-Thermopolis phases of the Colorado and the western edge of the Thermopolis "trough" of black shale deposits.
3. The thickness and character of Upper Colorado.
4. The shoreline of the Claggett Sea in this region.

The first two of these facts are of great importance in the exploration for oil; the last two are of interest as adding fixed points to the general knowledge of the Cretaceous history of the northern plains region.

GLACIAL DRIFT

The plains around the three buttes are abundantly mantled with glacial drift. Transported boulders are frequent and are chiefly Precambrian rocks from the main range of the Rocky Mountains, 100 miles to the west. The drift lies with an irregular surface, and in its inequalities are small ponds in the area to the east of West Butte.

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